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CHEMICAL WARFARE AGENT DECONTAMINATION EFFICACY TESTING LARGE-SCALE CHAMBER mVHP® DECONTAMINATION SYSTEM EVALUATION

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From Science to Solutions

SCIENCE APPLICATIONS
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14. ABSTRACT:
The STERIS Vaporous Hydrogen Peroxide (VHP) technology has been used for more than a decade to sterilize pharmaceutical processing equipment and clean rooms. Through a joint partnership, the U.S. Army Edgewood Chemical Biological Center (ECBC), and STERIS Corporation, Inc., a subsidiary of Strategic Technology Enterprises, began the process to co-develop a modified VHP (mVHP) capable of biological and chemical decontamination. Significant improvements have been made through a series of laboratory, chamber-scale, and large-scale efforts. The primary objective of this test was to determine the mVHP system's ability to decontaminate chemical-warfare agent contamination on operationally relevant materials. The decontamination efficacy was compared to the Key Performance Parameters (KPPs) stated in the Operational Requirements Document (ORD) for Joint Platform Interior Decontamination. In addition, tests were conducted at higher challenges, and cross-comparison tests were conducted to enable comparison to the KPPs stated in the ORD for Joint Service Sensitive Equipment Decontamination. The tests were performed between October 2005 and March 2006 in the Engineering Directorate large-scale chambers at the ECBC, APG, MD. The results for the chemical agent studies are presented in this report.

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PREFACE

The work described in this report was authorized under Project No. W9115R-04-C-0024. The work was started in October 2005 and completed in August 2006.

The work in this report pre-dates the 2007 Source Document, updated test method, and technology evaluation approaches that have occurred since summer 2006. The findings in this report were based on the methodologies and approaches as of the summer 2006 preparation date.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. Manufacturer names and model numbers are provided for completeness. This technical report may not be cited for purposes of advertisement.

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This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Service.

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CONTENTS

1. INTRODUCTION 1

1.1 Summary of Conclusions 2
1.2 The mVHP® Decontamination Process 7

2. METHODS AND PROCEDURES 10

2.1 Engineering Directorate Chamber Facilities 10
2.2 Decontamination Chamber 10
2.3 Test Materials 11
2.4 Chemical Agents 13
2.5 Coupon Contamination Method 13
2.6 Decontamination Efficacy Targets 13
2.7 Unique Identifier Code 14
2.8 Coupon Placement 15
2.9 mVHP Decontamination Process 16
2.10 Decontamination Test Methods 16
2.10.1 Contact-Hazard and Residual-Agent Analysis 16
2.10.2 Vapor Test Analysis 16
2.11 Analytical Procedures 19
2.11.1 Vapor Analysis 19
2.11.2 Contact Test Extraction and Analysis 20
2.12 Data Analysis Methods 21
2.12.1 Calibration Methods 21
2.12.2 Calculations and Unit Conversions 21
2.12.3 Suspect Data Points 22
2.12.4 Data Treatment 22
2.12.5 Data Presentation 22
2.12.6 ORD Factors 23
2.12.7 JSSED ORD Comparisons 24
2.13 Pre-wipe Process 25
2.14 Chemical Indicators (CI) 25
2.15 Types of Testing 26

3. TEST RESULTS AND DISCUSSION: ENGINEERING TEST 27

3.1 Test Summary 27
3.2 Process Results 28
3.3 CI Results and Discussion 29
3.4 Decontamination Chamber Coupon-Handling Process 30

4. MVHP PROCESS RESULTS AND SUMMARY 32

4.1 Test Summary 32
4.2 CT Results 32
4.3 Four-Phase Process 32
4.4 Sensitive Equipment Decontamination (SED) Prototype Cycle Time 32
4.5 Hydrogen Peroxide Consumption 34

5. TEST RESULTS AND DISCUSSION: HD 1 g/m^2 TEST ... 35

5.1 Test Summary for HD 1 g/m^2 Starting Challenge ... 35
5.2 Vapor Test Results for HD 1 g/m^2 Starting Challenge ... 36
5.3 Vapor Test Results Compared to ORDs for HD 1 g/m^2 Starting Challenge ... 39
5.4 Contact Test Results for HD 1 g/m^2 Starting Challenge ... 40
5.5 Contact Test Results Compared to ORDs for HD 1 g/m^2 Starting Challenge ... 48

6. TEST RESULTS AND DISCUSSION: HD 10 g/m^2 TEST ... 50

6.1 Test Summary for HD 10 g/m^2 Starting Challenge ... 50
6.2 Vapor Test Results for HD 10 g/m^2 Starting Challenge ... 51
6.3 Vapor Test Results Compared to ORDs for HD 10 g/m^2 Starting Challenge ... 53
6.4 Contact Test Results for HD 10 g/m^2 Starting Challenge ... 54
6.5 Contact Test Results Compared to ORDs for HD 10 g/m^2 Starting Challenge ... 61

7. TEST RESULTS AND DISCUSSION: TGD 1 g/m^2 TEST ... 63

7.1 Test Summary for TGD 1 g/m^2 Starting Challenge ... 63
7.2 Vapor Test Results for TGD 1 g/m^2 Starting Challenge ... 63
7.3 Vapor Test Results Compared to ORDs for TGD 1 g/m^2 Starting Challenge ... 66
7.4 Contact Test Results for TGD 1 g/m^2 Starting Challenge ... 68
7.5 Contact Test Results Compared to ORD for TGD 1 g/m^2 Starting Challenge ... 77

8. TEST RESULTS AND DISCUSSION: TGD 10 g/m^2 TEST ... 80

8.1 Test Summary for TGD 10 g/m^2 Starting Challenge ... 80
8.2 Vapor Test Results for TGD 10 g/m^2 Starting Challenge ... 80
8.3 Vapor Test Results Compared to ORDs for TGD 10 g/m^2 Starting Challenge ... 82
8.4 Contact Test Results for TGD 10 g/m^2 Starting Challenge ... 84
8.5 Contact Test Results Compared to ORDs for TGD 10 g/m^2 Starting Challenge ... 90

9. TEST RESULTS AND DISCUSSION: VX 1 g/m^2 TEST ... 93

9.1 Test Summary for VX 1 g/m^2 Starting Challenge ... 93
9.2 Vapor Test Results for VX 1 g/m^2 Starting Challenge ... 94
9.3 Vapor Test Results Compared to ORDs for VX 1 g/m^2 Starting Challenge ... 97
9.4 Contact Test Results for VX 1 g/m^2 Starting Challenge ... 99
9.5 Contact Test Results Compared to ORDs for VX 1 g/m^2 Starting Challenge ... 110

10. TEST RESULTS AND DISCUSSION: GD 1 g/m^2 TEST ... 112

10.1 Test Summary for GD 1 g/m^2 Starting Challenge ... 112
10.2 Vapor Test Results for GD 1 g/m^2 Starting Challenge ... 112
10.3 Vapor Test Results Compared to ORDs for GD 1 g/m^2 Starting Challenge ... 115
10.4 Contact Test Results for GD 1 g/m^2 Starting Challenge ... 117
10.5 Contact Test Results Compared to ORDs for GD 1 g/m^2 Starting Challenge ... 127

11. CHALLENGES AND LESSONS LEARNED ... 129

11.1 Challenging Test Conditions and Materials ... 129
11.2 Improved Test Design ... 129

11.3 mVHP Technology Optimization 129
11.4 Methods Improvement – Coupon Testing 130
11.5 Methods Improvement – Equipment Testing 130
11.6 When to Apply the Pre-Wipe 132
11.7 Warm versus Ambient Baseline Test 132
11.8 Material Observations and Other Comparisons 132
11.9 2004 Chamber Test 132
11.10 Low-End VX Calibration Challenge 134
11.11 Extraction Solvent Selection 134
11.12 Cross Contamination Blanks 134

LITERATURE CITED 137

ACRONYMS 139

APPENDIXES

A. COUPON STOCK MATERIAL AND PREPARATION 141
B. CONTROL CHARTS 143
C. ANALYTICAL INSTRUMENTATION PARAMETERS 171
D. COUPON CHAIN-OF-CUSTODY (COC) CARD 177

FIGURES

1. mVHP® decontamination chemistry illustration. 8
2. mVHP® decontamination cycle representation. 9
3. Lexan replica of STERIS SED prototype. 11
4. Chemical and biological test coupons. 12
5. Coupon contamination and aging in air-tight container. 13
6. Efficacy test example showing coupon arrangement, placement, and coding. 15
7. Contact test photograph of coupon, sampler, and weight. 17
8. Vapor test cup photograph. 18
9. Vapor concentration vs. time showing evaporation only. 18
10. Vapor concentration vs. time using a decontaminant. 19
11. Pre-wipe process photograph. 25
12. Chemical indicator before and after exposure to mVHP. 26
13. Coupon life cycle. 26
14. Engineering test dish numbers and CI locations. 28
15. Engineering test control charts. 29
16. Engineering test CI results. 30
17. Chamber coupon operation photographs. 31
18. HD vapor concentration vs. time for glass and polycarbonate. 36
19. HD vapor concentration vs. time for AF topcoat and CARC. 37
20. HD vapor concentration vs. time for silicone and Viton. 38
21. HD vapor concentration vs. time for aluminum and Kapton. 38
22. HD contact concentration vs. time for AF topcoat. 41
23. HD contact concentration vs. time for aluminum. 42
24. HD contact concentration vs. time for CARC. 43
25. HD contact concentration vs. time for glass. 44
26. HD contact concentration vs. time for Kapton. 45
27. HD contact concentration vs. time for polycarbonate. 46
28. HD contact concentration vs. time for silicone. 47
29. HD contact concentration vs. time for Viton 48
30. HD vapor concentration vs. time for glass and polycarbonate. 52
31. HD vapor concentration vs. time for CARC and silicone. 53
32. HD contact concentration vs. time for Aluminum (10 g/m^2 starting challenge). 55
33. HD contact concentration vs. time for CARC (10 g/m^2 starting challenge). 56
34. HD contact concentration vs. time for glass (10 g/m^2 starting challenge). 58
35. HD contact concentration vs. time for polycarbonate (10 g/m^2 starting challenge). 59
36. HD contact concentration vs. time for silicone (10 g/m^2 starting challenge). 60
37. TGD vapor concentration vs. time for glass and polycarbonate. 64
38. TGD vapor concentration vs. time for AF topcoat and CARC. 65
39. TGD vapor concentration vs. time for silicone and Viton. 65
40. TGD vapor concentration vs. time for aluminum and Kapton. 66
41. TGD contact concentration vs. time for AF topcoat. 69
42. TGD contact concentration vs. time for aluminum. 70
43. TGD contact concentration vs. time for CARC. 71
44. TGD contact concentration vs. time for glass. 72
45. TGD contact concentration vs. time for Kapton. 73
46. TGD contact concentration vs. time for polycarbonate. 74
47. TGD contact concentration vs. time for silicone. 75

48. TGD contact concentration vs. time for Viton. ... 76
49. TGD vapor concentration vs. time for glass, polycarbontate, and aluminum ... 81
50. TGD vapor concentration vs. time for CARC and silicone. ... 82
51. TGD contact concentration vs. time for aluminum (10 g/m² starting challenge). ... 85
52. TGD contact concentration vs. time for CARC (10 g/m² starting challenge) ... 86
53. TGD contact concentration vs. time for Glass (10 g/m² starting challenge) ... 87
54. TGD contact concentration vs. time for polycarbonate (10 g/m² starting challenge). ... 88
55. TGD contact concentration vs. time for silicone (10 g/m² starting challenge). ... 89
56. VX vapor concentration vs. time for glass and polycarbonate. ... 95
57. VX vapor concentration vs. time for AF topcoat and CARC. ... 95
58. VX vapor concentration vs. time for silicone and Viton. ... 96
59. VX vapor concentration vs. time for aluminum and Kapton. ... 97
60. VX contact concentration vs. time for AF topcoat. ... 100
61. VX contact concentration vs. time for aluminum. ... 101
62. VX contact concentration vs. time for CARC. ... 102
63. VX contact concentration vs. time for glass. ... 103
64. VX contact concentration vs. time for Kapton. ... 104
65. VX contact concentration vs. time for polycarbonate ... 105
66. VX contact concentration vs. time for silicone. ... 106
67. VX contact concentration vs. time for Viton. ... 107
68. GD vapor concentration vs. time for glass and polycarbonate ... 113
69. GD vapor concentration vs. time for AF topcoat and CARC. ... 114
70. GD vapor concentration vs. time for silicone and Viton. ... 114
71. GD vapor concentration vs. time for aluminum and Kapton. ... 115
72. GD contact concentration vs. time for AF topcoat. ... 118
73. GD contact concentration vs. time for aluminum. ... 119
74. GD contact concentration vs. time for CARC. ... 120
75. GD contact concentration vs. time for glass. ... 121
76. GD contact concentration vs. time for Kapton. ... 122
77. GD contact concentration vs. time for polycarbonate ... 123
78. GD contact concentration vs. time for silicone. ... 124
79. GD contact concentration vs. time for Viton. ... 125
80. Representation of mVHP sweet spot with optimization. ... 130
81. Method development for actual articles and live-agent testing. ... 131
82. 2004 Chamber test results show longer treatment times ... 133

TABLES

1. Best decontamination vapor test results (1 g/m² starting challenge only). ... 4
2. Best decontamination contact test results (1 g/m² starting challenge only). ... 5
3. Agent-material interactions – ability to reach ORD for vapor test (1 g/m² starting challenge only). ... 7
4. Agent-material interactions – ability to reach ORD for contact test, 1 g/m² starting challenge only, 15M test only. ... 7
5. Operational requirements document (ORD) performance values. ... 14
6. Nominal calibration masses for vapor test analysis (ng). ... 20
7. Nominal calibration concentrations for contact test analysis (ng/µL). ... 20
8. Example data table for contact test. ... 23
9. Example ORD comparison table. ... 24

10. Run configurations. 33
11. Exposure times and CT values for HD and TGD. 34
12. Exposure times and CT values for VX and GD. 35
13. SED prototype replica hydrogen peroxide consumption for 500 ppm target. 35
14. HD 1 g/m^2 starting challenge vapor results for glass and polycarbonate. 36
15. HD 1 g/m^2 starting challenge vapor results for AF topcoat and CARC. 37
16. HD 1 g/m^2 starting challenge vapor results for silicone and Viton. 37
17. HD 1 g/m^2 starting challenge vapor results for aluminum and Kapton. 38
18. Vapor ORD values for HD. 39
19. Vapor efficacy of mVHP on HD: 1 g/m^2 starting challenge. 40
20. HD 1 g/m^2 starting challenge contact test results for AF topcoat. 41
21. HD 1 g/m^2 starting challenge contact test results for aluminum. 42
22. HD 1 g/m^2 starting challenge contact test results for CARC. 43
23. HD 1 g/m^2 starting challenge hazard contact results for glass. 44
24. HD 1 g/m^2 starting challenge contact test results for Kapton. 44
25. HD 1 g/m^2 starting challenge contact test results for polycarbonate. 45
26. HD 1 g/m^2 starting challenge contact test results for silicone. 46
27. HD 1 g/m^2 starting challenge contact test results for Viton. 47
28. Contact ORD values for HD. 49
29. HD 1 g/m^2 starting challenge contact test residual agent results for all materials. 49
30. HD 1 g/m^2 starting challenge contact test results compared to ORD. 51
31. HD 10 g/m^2 starting challenge vapor test data for glass and polycarbonate. 52
32. HD 10 g/m^2 starting challenge vapor test data for CARC and silicone. 52
33. Vapor ORD values for HD. 54
34. HD 10 g/m^2 starting challenge vapor test results compared to ORDs for the combination of pre-wipe and mVHP methods. 54
35. HD 10 g/m^2 starting challenge vapor test results compared to ORDs for mVHP only. 54
36. HD 10 g/m^2 starting challenge contact test results for aluminum. 55
37. HD 10 g/m^2 starting challenge contact test results for CARC. 56
38. HD 10 g/m^2 starting challenge contact test results for glass. 57
39. HD 10 g/m^2 starting challenge contact test results for polycarbonate. 58
40. HD 10 g/m^2 starting challenge contact test results for silicone. 59
41. HD 10 g/m^2 starting challenge contact test residual agent results for all materials. 60
42. Contact ORD values for HD. 62
43. Evaluation of pre-wipe method (exclusively) on HD 10 g/m^2 starting challenge. 62
44. Evaluation of contact test results for mVHP with pre-wipe on HD 10 g/m^2 starting challenge. 62
45. Evaluation of mVHP (exclusively) on HD 10 g/m^2 starting challenge. 63
46. TGD 1 g/m^2 starting challenge vapor results for glass and polycarbonate. 64
47. TGD 1 g/m^2 starting challenge vapor results for AF topcoat and CARC. 64
48. TGD 1 g/m^2 starting challenge vapor results for silicone and Viton. 65
49. TGD 1 g/m^2 starting challenge vapor results for aluminum and Kapton. 66
50. Vapor ORD values for TGD. 67
51. Vapor efficacy of mVHP on TGD: 1 g/m^2 starting challenge. 67
52. TGD 1 g/m^2 starting challenge contact test results for AF topcoat. 69
53. TGD 1 g/m^2 starting challenge contact test results for aluminum. 70
54. TGD 1 g/m^2 starting challenge contact test results for CARC. 71
55. TGD 1 g/m^2 starting challenge hazard contact results for glass. 72
56. TGD 1 g/m^2 starting challenge contact test results for Kapton. 72
57. TGD 1 g/m^2 starting challenge contact test results for polycarbonate. 73
58. TGD 1 g/m^2 starting challenge contact test results for silicone. 74

59. TGD 1 g/m² starting challenge contact test results for Viton. 75
60. TGD 1 g/m² starting challenge contact test residual agent results for all materials. 76
61. Contact ORD values for TGD. 78
62. TGD 1 g/m² starting challenge contact test results compared to ORD. 79
63. TGD 10 g/m² starting challenge vapor test data for glass and polycarbonate. 80
64. TGD 10 g/m² starting challenge vapor test data for CARC and silicone. 81
65. Vapor ORD values for TGD. 83
66. TGD 10 g/m² starting challenge vapor test results compared to ORDs for pre-wipe and mVHP. 83
67. TGD 10 g/m² starting challenge vapor test results compared to ORDs for mVHP only. 83
68. TGD 10 g/m² starting challenge contact test results for aluminum. 84
69. TGD 10 g/m² starting challenge contact test results for CARC. 85
70. TGD 10 g/m² starting challenge contact test results for glass. 86
71. TGD 10 g/m² starting challenge contact test results for polycarbonate. 87
72. TGD 10 g/m² starting challenge contact test results for silicone. 88
73. TGD 10 g/m² starting challenge contact test residual agent results for all materials. 89
74. Contact ORD values for TGD. 91
75. Evaluation of pre-wipe method (exclusively) on TGD 10 g/m² starting challenge. 92
76. Evaluation of contact test results for mVHP with pre-wipe on TGD 10 g/m² starting challenge. 92
77. Evaluation of mVHP (exclusively) on TGD 10 g/m² starting challenge. 93
78. VX 1 g/m² starting challenge vapor results for glass and polycarbonate. 94
79. VX 1 g/m² starting challenge vapor results for AF topcoat and CARC. 95
80. VX 1 g/m² starting challenge vapor results for silicone and Viton. 96
81. VX 1 g/m² starting challenge vapor results for aluminum and Kapton. 96
82. Vapor ORD values for VX. 98
83. Vapor efficacy of mVHP on VX: 1 g/m² starting challenge. 98
84. VX 1 g/m² starting challenge contact test results for AF topcoat. 99
85. VX 1 g/m² starting challenge contact test results for aluminum. 100
86. VX 1 g/m² starting challenge contact test results for CARC. 101
87. VX 1 g/m² starting challenge contact test results for glass. 102
88. VX 1 g/m² starting challenge contact test results for Kapton. 103
89. VX 1 g/m² starting challenge contact test results for polycarbonate. 104
90. VX 1 g/m² starting challenge contact test results for silicone. 105
91. VX 1 g/m² starting challenge contact test results for Viton. 106
92. VX 1 g/m² starting challenge contact test residual agent results for all materials. 108
93. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results. 109
94. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results. 109
95. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results. 109
96. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results. 109
97. VX 10 g/m² starting challenge efficacy test (run 30). 110
98. Contact ORD values for VX. 111
99. VX 1 g/m² starting challenge contact test results compared to ORD. 111
100. VX 10 g/m² starting challenge comparison to JSSED ORD for pre-wipe method only. 112
101. GD 1 g/m² starting challenge vapor results for glass and polycarbonate. 113
102. GD 1 g/m² starting challenge vapor results for AF topcoat and CARC. 113
103. GD 1 g/m² starting challenge vapor results for silicone and Viton. 114

104. GD 1 g/m^2 starting challenge vapor results for aluminum and Kapton. 115
105. Vapor ORD values for GD. 116
106. Vapor efficacy of mVHP on GD: 1 g/m^2 starting challenge. 116
107. GD 1 g/m^2 starting challenge contact test results for AF topcoat. 118
108. GD 1 g/m^2 starting challenge contact test results for aluminum. 119
109. GD 1 g/m^2 starting challenge contact test results for CARC. 120
110. GD 1 g/m^2 starting challenge hazard contact results for glass. 121
111. GD 1 g/m^2 starting challenge contact test results for Kapton. 122
112. GD 1 g/m^2 starting challenge contact test results for polycarbonate. 123
113. GD 1 g/m^2 starting challenge contact test results for silicone 124
114. GD 1 g/m^2 starting challenge contact test results for Viton. 125
115. GD 1 g/m^2 starting challenge contact test residual agent results for all materials. 125
116. Contact ORD values for GD. 127
117. GD 1 g/m^2 starting challenge contact test results compared to ORD. 128
118. Contact test results for VX 10 g/m^2 starting challenge with pre-wipe and mVHP on a DVD player. 131
119. Comparison to ORD for contact test results for VX 10 g/m^2 starting challenge with pre-wipe and mVHP on a DVD player. 132

CHEMICAL WARFARE AGENT DECONTAMINATION EFFICACY TESTING LARGE-SCALE CHAMBER mVHP® DECONTAMINATION SYSTEM EVALUATION

1. INTRODUCTION

The STERIS Vaporous Hydrogen Peroxide (VHP) technology has been used for more than a decade to sterilize pharmaceutical processing equipment and clean rooms.[1, 2] In October 2001, the VHP technology was adapted to decontaminate two anthrax-contaminated buildings in the Washington, D.C. area. In 2002, STERIS Corporation, Inc., subsidiary, Strategic Technology Enterprises (STE), and the U.S. Army Edgewood Chemical Biological Center (ECBC) began to co-develop a modified VHP (mVHP) capable of both biological and chemical decontamination. Over the past few years, the mVHP fumigant has been significantly improved for the decontamination of materials contaminated with chemical agents VX, GD, and HD.[3] The mVHP technology was developed and patented through a Cooperative Research and Development Agreement (CRADA) between ECBC and STE. During this time, the mVHP system was also improved to enable better distribution and higher concentrations. The mVHP technology is scalable and adaptable to accommodate a broad range of applications, such as buildings, aircraft, and sensitive equipment. Many programs were executed during this time to demonstrate application and determine agent efficacy.[4] The modular mVHP™ system was successfully demonstrated in a former office building decontamination tests at the Aberdeen Proving Grounds (APG) in Maryland and C-141B aircraft decontamination tests at Davis-Monthan AFB in Arizona.[5-7] The biological chambers and BSL-3 laboratory tests were used to determine the decontamination efficacy against biological agent and surrogate on operationally relevant materials. The chemical chambers work was performed to determine the decontamination efficacy against chemical agents HD, VX, TGD, and GD on operationally relevant materials. The VHP/mVHP decontamination tests and demonstrations are part of a congressionally funded joint venture between ECBC and STE.

In 2004, a VHP decontamination chamber study, utilizing a modified Sensitive Equipment Decontamination (SED) box, showed that biological simulant could be decontaminated on sensitive equipment within four hours. This finding was the first significant step toward the application of the mVHP technology to the Joint Service Sensitive Equipment Decontamination (JSSED) program. In June 2005, a SED prototype was evaluated for operational utility at the Decontamination Limited Objective Experiment (LOE) at Tyndall AFB. The LOE formal report indicated that mVHP has potential applicability for thorough decontamination of sensitive equipment, primarily in rear echelon applications as currently configured on the 463L pallet. Following the LOE, the SED prototype was brought to full decontamination capability. The operational SED prototype was sent to ECBC for both sensitive equipment surrogates and biological surrogate decontamination efficacy evaluations.[8] The prototype utilized mVHP for chemical- and biological-agent decontamination application, and improved fumigant distribution and delivery methods. The improved methods enabled higher concentrations of peroxide in field applications. The approach for the chamber chemical agent and biological surrogate testing was to construct a replica of the SED prototype decontamination chamber for use under engineering controls. Use of the replica enabled a complete evaluation of the STERIS mVHP technology: mVHP fumigant, distribution, and operating conditions. The replica provided an additional advantage as a tie-in point from lab (agent) to field (surrogate) data.

VHP® is a registered trademark of STERIS Corporation, 5960 Heisley Road, Mentor, OH 44060.

The primary objective of this test was to determine the mVHP system's ability to decontaminate chemical-warfare agent contamination on operationally relevant materials. The decontamination efficacy was compared to the Key Performance Parameters (KPPs) stated in the Operational Requirements Document (ORD) for Joint Platform Interior Decontamination (JPID).[9] The decontamination efficacy was also compared to the KPPs stated in the ORD for JSSED.[10] The tests were performed between October 2005 and March 2006 in the Engineering Directorate large-scale chambers at the ECBC. The results for the chemical agent studies are presented in this report.

1.1 Summary of Conclusions

The purpose of this test was to determine the mVHP system ability to decontaminate chemical-warfare agent contamination on operationally relevant materials. Test results were evaluated based on meeting ORD values, using the approaches identified in this report, and based on the guidance available at this time.

For the conclusions presented here, if there were data points for equivalent tests (e.g., scoping vs. efficacy runs) the results will represent the worst-case response (i.e., the response showing the greatest remaining hazard). The summary of conclusions is provided in the following list:

ORD KPP Overall Summary: The following list contains the summary of the ORD contact and vapor requirements and facts.

- The test results show that mVHP can decontaminate all tested agents (HD, GD, TGD, and VX) on the eight materials evaluated.
- The data was compared to both the JPID and JSSED ORD (Section 2.6) threshold and objective values.
  - The threshold value is a higher value than the objective value.
  - The JPID ORD specifies a 1 g/m^2 starting challenge.
  - The JSSED ORD specifies a 10 g/m^2 starting challenge.
  - The result comparisons are based on the JPID objective value.
  - The JPID ORD objective factor is described in Section 2.12.6. The ORD factors correspond to the ratio of the measured value to the corresponding ORD value.
    - An ORD Factor value $\leq .0$ passes the ORD; a value >1.0 fails to meet the specified ORD.
    - The ORD values for each agent are presented in Table 5.
    - An ORD factor of 2.0 corresponds to the measured value being twice as great as the specified ORD.
  - Some material and agent combinations did not achieve ORD objective requirements within the test's duration. The potential of these combinations to meet ORD requirements exists with system optimization.

Operational Summary: The following list contains the technical report summary for the operational performance of the mVHP system used.

- The mVHP system demonstrated the ability to reach the target 500 ppm hydrogen peroxide and 30 ppm ammonia concentration in a simulated operational environment (SED Box).
  - The fumigant concentrations were based on the current prototype systems. The technology had not yet been optimized to reduce cycle time.
- The mVHP-required processing conditions for temperature, relative humidity, and fumigant concentration were achievable in the SED box replica.

- A statistical analysis of the chamber test Lexan replica data and the SED prototype data, demonstrated that the Lexan replica was statistically equivalent to the SED system prototype.
  - The chemical agent data presented here is representative of the anticipated performance in the actual SED prototype. Thus, these results are applicable to a simulated relevant environment.
  - Hydrogen peroxide consumption and cycle time can be projected based on the SED prototype operation.

Vapor-Hazard Summary: The following list contains the technical report summary for the direct comparison of the vapor test data to the vapor hazard requirement values.

- The required decontamination time to reach ORD varies by agent and material.
- Table 1 summarizes the most decontaminated vapor test results for the time points acquired in this analysis.
  - **HD** – Good performance was observed for HD:
    - Six of eight materials were decontaminated to less than the JPID objective ORD (0.003 mg/m^3).
    - Polycarbonate and Viton were decontaminated to 2.9 and 12 times greater than the JPID objective ORD.
  - **GD** – Mixed performance was observed during the GD tests:
    - GD was the first agent performed during the chamber test.
    - Glass, polycarbonate, and silicone were decontaminated to less than the JPID objective ORD (0.0002 mg/m^3).
    - Aluminum met the JPID threshold ORD, but was 1.9 times greater than the JPID objective ORD.
    - Kapton and CARC were decontaminated to 5.4 and 8.9 times greater than the JPID objective ORD, respectively.
    - AF topcoat and Viton were decontaminated to 27 and 13 times greater than the JPID objective ORD.
    - The cross-contamination blanks showed the presence of some GD that was later attributed to a handling problem.
  - **TGD** – Good performance was observed for TGD:
    - Seven of eight materials were decontaminated to less than the JPID objective ORD (0.0002 mg/m^3).
    - AF topcoat met the JPID threshold ORD, but was 1.7 times greater the JPID objective ORD.
    - The handling problem experienced with GD was resolved by minimizing cross contamination during movement from the chamber to the test location.
  - **VX** – Performance was split, based on nonporous and porous surfaces:
    - Aluminum, glass, polycarbonate, and Kapton were decontaminated to less than the JPID objective ORD (0.000024 mg/m^3).
    - AF topcoat, CARC, and silicone were decontaminated less than 1.3 times the JPID objective ORD, which was approximately the JPID threshold ORD (0.000036 mg/m^3).
    - Viton emitted a compound that interfered with the analysis of VX. The result, which was 28 times the JPID objective ORD, was an overestimated hazard.
- Table 1 shows the best results acquired for the vapor test with a 1 g/m^2 starting challenge. The data fields are formatted using the *JPID objective ORD factor* over

exposure time. Exposure time corresponds to the time, in minutes, that the coupon was exposed to mVHP.

Table 1. Best decontamination vapor test results (1 g/m² starting challenge only).

Class	Material	Agent [ORD Factor/Exposure Time (min)]			
		HD	GD	TGD	VX
Metal	Aluminum	0.0 / 238	1.9 / 124	0.0 / 120	0.0 / 479
Glass	Glass	0.0 / 476	0.0 / 62	0.2 / 298	0.4 / 616
Plastics	Polycarbonate	2.9 / 476	0.0 / 62	0.6 / 298	0.2 / 616
	Kapton	0.0 / 235	5.4 / 124	0.0 / 120	0.2 / 616
Paints	AF Topcoat	0.0 / 479	27 / 239	1.7 / 480	1.2 / 595
	CARC	0.0 / 240	8.9 / 180	0.2 / 480	1.2 / 595
Elastomers	Silicone	0.0 / 477	0.0 / 62	0.0 / 240	1.6 / 595
	Viton	12 / 479	13 / 239	0.0 / 240	28* / 595

* There was a known VX interferent vapor emitted from Viton, this number is artificially high.

Contact-Hazard Summary: The following list contains the technical report summary for the direct comparison of the contact test data to the contact hazard requirement values.

- The required decontamination time to reach ORD varies by agent and material.
- Table 2 summarizes the most decontaminated contact test results for the time points acquired in this analysis.
  - **HD** – Good performance was observed for HD:
    - Seven of eight materials were decontaminated to below the JPID objective ORD (0.05 mg/m²).
    - Silicone was decontaminated to the JPID threshold ORD, which is 56 times greater than the JPID objective ORD.
  - **GD** – Good performance, except for porous materials was observed for GD:
    - Five of eight materials were decontaminated to below the JPID objective ORD (0.05 mg/m²).
    - AF topcoat, silicone, and Viton were 18, 54, and 43 times the JPID objective ORD.
  - **TGD** – Mixed performance was observed for TGD:
    - AF topcoat, CARC, and Viton were decontaminated below the JPID objective ORD (0.05 mg/m²).
    - Aluminum, glass, polycarbonate, and Kapton were decontaminated to near JPID objective ORD at a factor of three times greater than the ORD.
    - Silicone was decontaminated to 22 times greater the JPID objective ORD, which is well below the JPID threshold ORD.
  - **VX** – Mixed performance was observed for VX:
    - Only aluminum was decontaminated to below the JPID objective ORD for the 15M test, and the 60M test exhibited contamination at 3.9 times the JPID objective ORD.
    - CARC and AF topcoat were decontaminated to less than nine times the JPID objective ORD.
    - Kapton was decontaminated to less than 22 times the JPID objective ORD.
    - Glass, polycarbonate, silicone, and Viton were at least 1400 times the JPID objective ORD.

- The VX tests were further challenged by the limitation of the analytical equipment to hold calibration at the ORD value. Cases where CCV correction was applied are denoted with (‡).

- Table 2 shows the best results acquired for the contact test with a 1 g/m² starting challenge. The exposure time is reported in minutes. The contact test involves two separate analyses, the 15M and 60M tests.

Table 2. Best decontamination contact test results (1 g/m² starting challenge only).

Class	Material	Agent							
		HD		GD		TGD		VX	
		Time (min)	15M/60M	Time (min)	15M/60M	Time (min)	15M/60M	Time (min)	15M/60M
Metal	Aluminum	240	0.0 / 0.0	124	0.0 / 0.0	298	2.8 / 1.6	241	0.0 / 3.9
Glass	Glass	235	0.0 / 0.0	124	0.0 / 0.0	298	3.0 / 2.1	241	1407 / 478
Plastics	Polycarb.	476	0.0 / 0.0	124	0.0 / 0.0	298	2.9 / 2.9	237	3066 / 2145
	Kapton	235	0.0 / 0.0	124	0.0 / 0.0	298	2.8 / 2.9	241	6.0 / 2.5
Paints	AF Topcoat	240	0.0 / 0.0	482	18 / 37	240	0.0 / 0.0	354	22 / 3.5
	CARC	240	0.0 / 0.0	180	0.0 / 0.0	240	0.0 / 0.0	354	8.3 / 5.4‡
Elastomers	Silicone	479	56 / 85	482	54 / 110	600	22 / 66	354	3284 / 1474
	Viton	240	0.0 / 0.0	482	43 / 79	480	0.0 / 0.0	354	5729 / 2875

‡ - CCV failed – data recovered using single point calibration of CCV, data is suspect.
NOTE: The JPID objective ORD factor is presented for both tests in the format of 15M ORD Factor / 60M ORD Factor.

Pre-Wipe Performance Summary: The following list contains the technical report summary for the subset of tests performed using a pre-wipe.

- The pre-wipe method removed agent from the coupon.
- Qualitative analysis showed that a 10 g/m² starting challenge, using the pre-wipe, provided the following results for:
  - **HD** and **TGD/GD**: a 10 g/m² starting challenge with pre-wipe can be reduced to less than a 1 g/m² starting challenge.
  - **VX**: the single-scoping test indicated that the 10 g/m² starting challenge with pre-wipe was not equivalent to a 1 g/m² starting challenge. Recommended that this test be revisited during optimization.
  - **HD** and **GD/TGD**: the 1 g/m² starting challenge data can be compared to the JSSED ORD values as representative of a 10 g/m² starting challenge that has been pre-wiped before mVHP decontamination.

Baseline Test Summary: The following list contains the technical report summary for the baseline tests using agent and the decontaminant process conditions without hydrogen peroxide or ammonia.

- In general, the baseline tests showed that chemical agent persisted on the coupon surfaces in the absence of the mVHP temperature, humidity, and fumigant concentration requirements.
- The "warm" TGD baseline showed a greater efficacy compared to the mVHP studies, using the mVHP temperature and humidity conditions in the absence of fumigant. The observed efficacy was a forced "warm" air effect that resulted in increased

weathering of agent from the coupon surface. In this case, it was believed that agent was relocated from the coupon to the exhaust air.

Agent-Material Interaction and Meeting ORD Summary: The following list contains the technical report summary for the appearance of material-agent-decontaminant interaction effects.

- The agent-material interaction was based on the time required to achieve JPID ORD values. The ORD values were based on increasing toxicity in the order of HD, GD/TGD, and VX. Since VX was greater in toxicity, additional decontamination was required to meet ORD when compared with HD.
- The time to decontaminate a material to meet the JPID objective ORD value depended on interaction between the agent and the material (e.g., wetting properties, porous vs. nonporous, and material incompatibilities).
- The ranking of "easier to reach ORD" was highly dependent on the ORD value. For example, the JPID contact objective ORD for HD is 0.05 mg/m^2 vs. 0.005 mg/m^2 for VX. This corresponds to decontaminating 99.995% of HD vs. 99.9995% of VX, a factor of ten times more decontamination. Thus, VX may be decontaminated to levels similar to HD, but due to the lower ORD values, the ORD factors would be about ten times higher for VX than HD. The difference in factors depended on the ORD type (JPID vs. JSSED) and the test type (contact vs. vapor). The most notable difference was for the JPID vapor objective ORD where HD is 0.003 mg/m^3 vs. 0.000024 mg/m^3 for VX, a difference factor of 125. However, differences in ORD factor results were most strongly dependent on the ability of mVHP to decontaminate a given agent.
- Table 3 ranks the difficulty of mVHP to decontaminate a given agent to the JPID vapor objective ORD. The time points used in this table were selected to be as similar as possible. Additionally, these time points were the shorter time periods of the experiments, thus many of the ORD factors would be greater than 1.0. In general, HD was the easiest to decontaminate, followed by TGD, with GD and VX being hardest to decontaminate.
- Table 4 ranks the difficulty of mVHP to decontaminate a given agent to the JPID contact objective ORD. The time points used in this table were selected to be as similar as possible. These time points were the shorter time periods of the experiments, thus many of the ORD Factors would be greater than 1.0. Similar to the vapor test results, HD tended to be the easier agent to reach ORD followed by TGD, GD, and VX.

Table 3. Agent-material interactions – ability to reach ORD for vapor test (1 g/m² starting challenge only).

Class	Material	Easier ◄---- 1	to reach ORD 2	---► 3	Harder 4
Metal	Aluminum	HD 0.0 / 235	TGD 0.0 / 120	GD 1.9 / 124	VX 0.4 / 616
Glass	Glass	TGD 0.2 / 298	VX 3.5 / 360	HD 38 / 235	GD 24 / 180
Plastics	Polycarbonate	TGD 0.9 / 241	GD 4.5 / 180	HD 28 / 235	VX 9.2 / 360
	Kapton	HD 0.0 / 235	TGD 0.0 / 120	VX 0.7 / 359	GD 5.4 / 124
Paints	AF Topcoat	TGD 5.2 / 240	HD 7.9 / 240	VX 5.4 / 354	GD 27 / 239
	CARC	HD 0.0 / 238	TGD 0.5 / 240	VX 3.1 / 360	GD 12 / 239
Elastomers	Silicone	TGD 0.0 / 240	VX 0.4 / 360	GD 19 / 239	HD 26 / 240
	Viton	TGD 0.0 / 240	GD 13 / 239	HD 28 / 240	VX 80* / 354

* There was a known VX interferent emitted from Viton; this number is artificially high.
NOTE: Data is presented as agent name, JPID vapor objective ORD factor/exposure time.

Table 4. Agent-material interactions – ability to reach ORD for contact test, 1 g/m² starting challenge only, 15M test only.

Class	Material	Easier ◄---- 1	to reach ORD 2	---► 3	Harder 4
Metal	Aluminum	HD 0.0 / 235	VX 0.0 / 241	TGD 2.8 / 298	GD 33 / 234
Glass	Glass	HD 0.0 / 235	TGD 3.0 / 298	GD 18 / 234	VX 1406 / 241
Plastics	Polycarbonate	HD 0.0 / 235	GD 0.0 / 234	TGD 2.9 / 298	VX 23 / 241
	Kapton	HD 0.0 / 235	TGD 2.8 / 298	VX 6.0 / 241	GD 31 / 234
Paints	AF Topcoat	HD 0.0 / 240	TGD 0.0 / 240	GD 32 / 239	VX 16040 / 272
	CARC	HD 0.0 / 240	TGD 0.0 / 240	GD 0.0 / 239	VX 3.3 / 237
Elastomers	Silicone	TGD 52 / 240	GD 94 / 239	HD 113 / 240	VX 3284 / 354
	Viton	HD 0.0 / 240	TGD 22 / 240	GD 67 / 239	VX 5729 / 354

Data is presented as agent name, JPID contact objective ORD factor (for 15M test only)/exposure time.

1.2 The mVHP® Decontamination Process

The mVHP is a broad-spectrum decontaminant, composed of vaporous hydrogen peroxide and a small amount of ammonia gas, used within a specified set of conditions. The mVHP decontamination process evaluated was the combination of the patented mVHP decontaminant and decontamination operating conditions.[11, 12]

The mVHP decontamination process has been shown to be effective at atmospheric pressure and at ambient temperatures. The process is completely vapor phase hydrogen peroxide and ammonia. Hydrogen peroxide vapor readily formed hydroxyl free radicals that have been found to react with various micromolecules. The VHP® rapidly decomposed into two environmentally benign products: oxygen and water vapor (Figure 1). Metal oxide catalysts were used for large-scale, once-through processes requiring more rapid decomposition on the exhaust stream. The process used up to 30 ppm of ammonia, which was below the Permissible Exposure Limit (PEL) of 50 ppm. Unreacted ammonia was scrubbed out of the exhaust air through an appropriate filter. The field systems monitored the exhaust for both ammonia and hydrogen peroxide to ensure no fumigant escaped the filter bed.

Because mVHP is a vapor technique, the primary requirement for decontamination was an enclosure. The technology is versatile—adaptable to enclosures ranging from defined boxes (e.g., SED), to vehicle and building interiors, to tents.[4, 13]

Decontamination of an interior/enclosed space, using the modular mVHP system, was a four-phase process involving preparation of the interior air (dehumidification), achieving a steady-state decontaminant level (conditioning), performing the decontamination, and then aerating the space for safe entry (Figure 2).

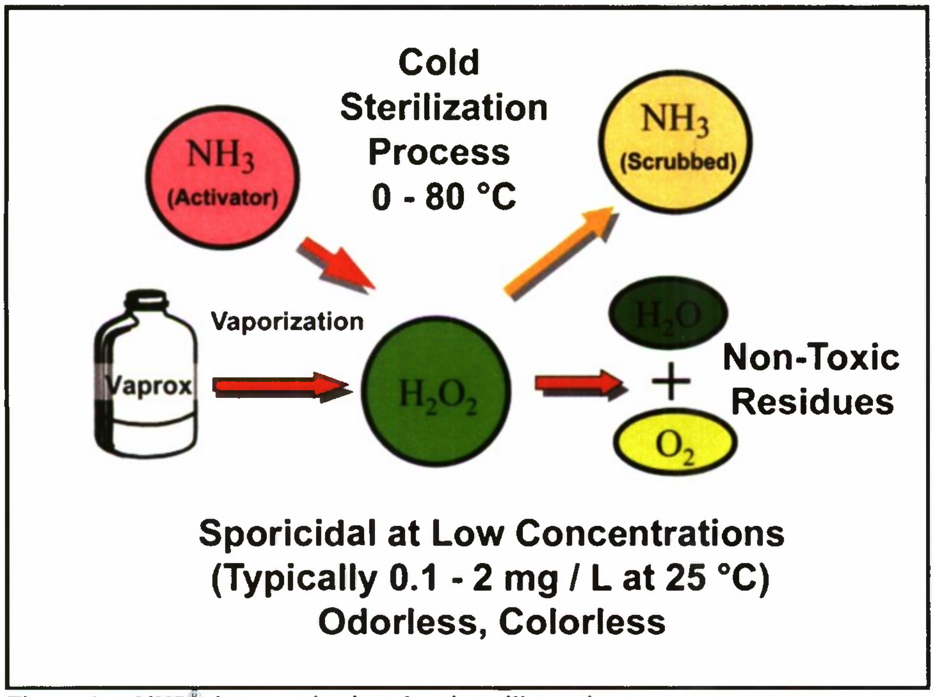

Figure 1. mVHP® decontamination chemistry illustration.

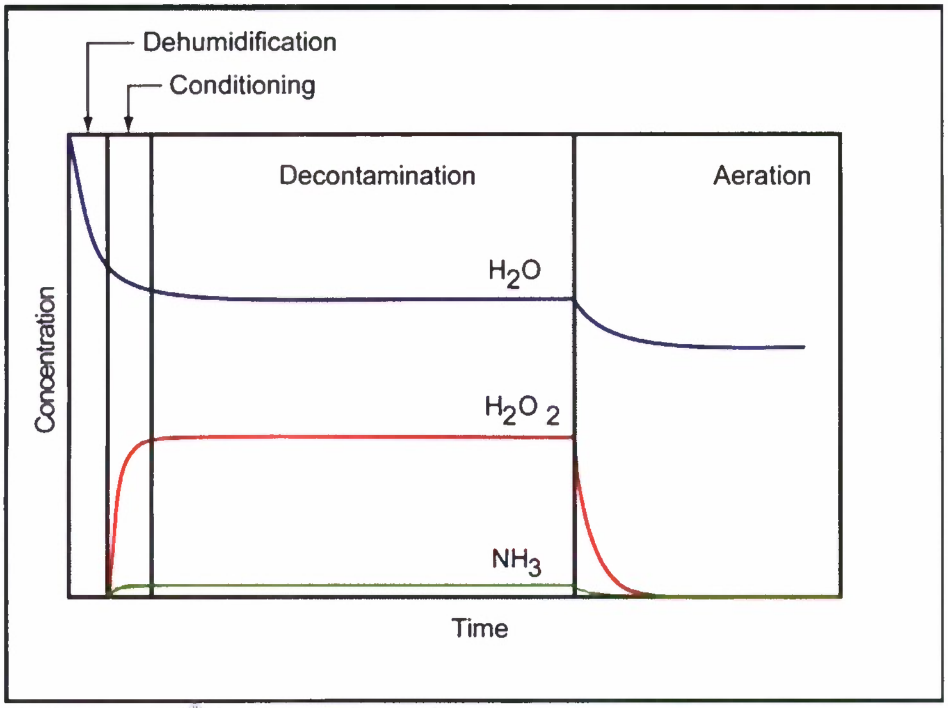

Figure 2. mVHP® decontamination cycle representation.

Dehumidification: Hydrogen peroxide vapor can co-condense with water vapor, producing an undesired condensate high in hydrogen peroxide. If ambient conditions are likely to permit condensation—high humidity and/or cold temperatures, this can be prevented by circulating dry, heated air through the interior before the hydrogen peroxide vapor injection. The target humidity level was determined by the vapor concentration to be injected and the desired steady-state decontamination concentration. The lower relative humidity permits a higher concentration of hydrogen peroxide without reaching a saturation point.

Conditioning: During the conditioning phase, injection of ammonia and hydrogen peroxide vapor was initiated. Injection rates were selected to rapidly raise the concentrations to the desired setpoint without condensation. Internal sensors measured and reported the ammonia and hydrogen peroxide concentrations to the control system. The ammonia and hydrogen peroxide injection rates were lowered to maintain the set-point concentrations when the concentrations reach the set-point values. The system proceeded to the next phase once all the interior monitors reached or exceeded the set-point concentration.

Decontamination: Decontamination was timed-phase dependent on the hydrogen peroxide vapor concentration, ammonia vapor concentration, and temperature. A decontamination timer counted down from the preset decontamination time. If the concentrations or temperature values fell below the set point, the timer stopped. This ensured that the interior space was exposed to at least the minimum decontamination conditions for the desired exposure time during the decontamination phase.

Aeration: The system stopped injection of hydrogen peroxide and ammonia, and introduced only dried air into the interior space after completion of the decontamination phase. The dried air displaced the hydrogen peroxide and ammonia. The hydrogen peroxide and ammonia were removed by the exhaust system. Samples were drawn and tested from the exhaust system upstream of the catalyst bed. The user terminated the aeration process when the measurements were below the ammonia and hydrogen peroxide PELs.

2. METHODS AND PROCEDURES

2.1 Engineering Directorate Chamber Facilities

The tests were conducted in one of the Engineering Directorate large-scale chambers at ECBC. The chamber contained the mVHP decontamination chamber, a working enclosure for sample dosing, and the vapor-manifold table. The chamber was monitored using miniature Chemical Agent Monitors (miniCAMs) for chemical agent, and Dräger sensors for ammonia and hydrogen peroxide concentration outside the mVHP decontamination chamber. The filter banks and control rooms were also monitored for chemical agent during testing.

The use of Personnel Protective Equipment (PPE) with mVHP is well understood. Since mVHP is a vapor-phase decontaminant, the safety requirements were based on the OSHA PEL values for both vapors. The ammonia and hydrogen peroxide PELs are 50 ppm and 1 ppm, respectively. The ammonia and hydrogen peroxide concentrations outside of the box were monitored during testing. If the ammonia or hydrogen peroxide concentrations were above allowable limits, Self-Contained Breathing Apparatus (SCBA) was used. SCBA was also used to protect operators, should any fumigant escape from the chamber, when samples were added to or removed from the decontamination chamber.

2.2 Decontamination Chamber

A replica of the SED prototype on the 463L pallet decontamination chamber was constructed for use in the ECBC Engineering Directorate Chamber Facility (Figure 3). The decontamination chamber provided a test enclosure with a similar volume, dimensions, fumigant distribution, and inlet and outlet ports characteristic of both the STERIS modular mVHP process and the SED prototype. The decontamination chamber was 8 ft long, 4 ft wide, and 7 ft tall. The enclosure was constructed from Lexan® as two 3.5 ft-tall half-boxes. The upper box sat over the lower box to create the decontamination chamber. The SED prototype contained shelves for the placement of equipment. The chamber replica had a stainless steel table fitted with a stainless steel mesh top for placement of the coupon containers. The SED prototype decontamination chamber was accessed via doors on the narrow sides of the unit. The use of full-size doors was not practical for the chamber testing since the tests focused on the required decontamination phase time. Opening a large door would result in higher loss of fumigant as samples were removed during the decontamination phase. The replica had two ports of entry: an access door and a small "pizza oven" door. The samples were placed in, and removed from, the decontamination chamber via the pizza oven door.

Lexan® is a registered trademark of SABIC Innovative Plastics, Riyadh, Saudi Arabia.

Features: Similar Fan Placements (●), Flow Profiles, Similar Inlet (●) and Exhaust Ports (●), Fumigant and Sensor locations

Figure 3. Lexan replica of STERIS SED prototype.

2.3 Test Materials

The test materials included bare aluminum, CARC-painted aluminum, AF topcoat-painted aluminum, glass, polycarbonate, Viton®, Kapton®, and silicone (Figure 4). The selected test materials spanned a variety of structural and functional materials common to aircraft, vehicles, and protective- and sensitive-equipment, which encompassed a variety of material properties, compositions, and porosities. The biological agent surrogate test coupons were 1.3 cm squares, except glass, which was round. The chemical agent test coupons were 2 in. circular disks with a surface area of 3.14 in.^{2} (0.002027 m^2). The glass chemical agent test coupons were ordered pre-cut from McMaster-Carr. All other chemical and biological test coupons were cut from stock material.

Vitron® is a registered trademark of Vitron Manufacturing, Phoenix, AZ
Kapton® is a register trademark of E.I. DuPont de Nemours and Company, Wilmington, DE.

A large quantity of material was used for the preparation of multiple test samples to assure uniform characteristics. (e.g., Test coupons were all cut from the interior rather than the edge of a large piece of material.) All coupons were stored in zip-tight bags, which were placed in containers to prevent/limit contact with foreign substances until they were needed for testing. The biological test coupons were sterilized before use. The coupon preparation information, including material vendors and descriptions, is provided in Appendix A. For all materials except polycarbonate, sufficient coupons were available to complete the testing. TGD baseline rerun test 26, VX repeat tests 17R and 30, and HD Efficacy A used Decon Sciences polycarbonate rather than JSSED polycarbonate. Laboratory tests to determine application of the wipe did not show a difference between the two materials. Additionally, laboratory pre-wipe scoping tests did not indicate a difference between the two materials.

Figure 4. Chemical and biological test coupons.

2.4 Chemical Agents

Chemical agents HD and GD were Chemical Agent Standard Reference Material (CASARM) grade. Chemical agent VX was "high purity" grade. All agents were obtained from the Chemical Transfer Facility at ECBC. The relative molar purity of VX was determined by 31P Nuclear Magnetic Resonance (NMR) to be 94.81%. One vial of each agent was sufficient to execute all tests, thus there were no lot variations in this data set.

2.5 Coupon Contamination Method

The coupons were contaminated with the appropriate chemical agent at a contamination density (i.e., starting challenge) of either 1 or 10 g/m^2. Chemical agents VX, TGD, and GD were applied as four 0.5 µL drops from a repeater syringe to achieve the 1 g/m^2 contamination density. Chemical agent TGD was applied as four 5.0 µL drops from a repeater pipette to achieve the 10 g/m^2 contamination density. Chemical agent HD was applied as three 0.5 µL drops from a repeater syringe to achieve the 1 g/m^2 contamination density. Chemical agent HD was applied as four 4.0 µL drops from a repeater pipette to achieve the 10 g/m^2 contamination density. Syringes were checked for air bubbles, and initial drops were made on M8 paper. The calculations showing the relationship between coupon area and contamination density for each agent are provided in Appendix B. After contamination the coupons were aged for one hour in closed Tupperware® containers as seen in Figure 5. The lid was removed after aging, and the container was placed into the decontamination chamber.

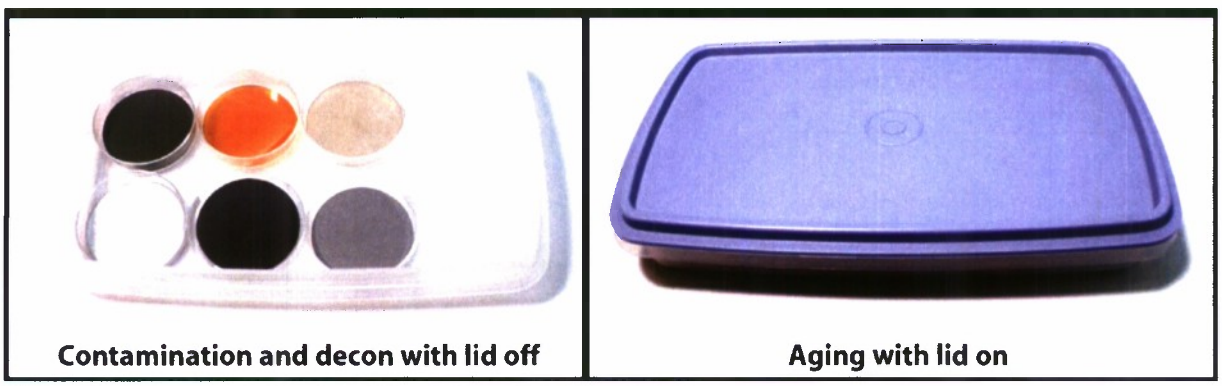

Figure 5. Coupon contamination and aging in air-tight container.

2.6 Decontamination Efficacy Targets

Decontamination efficacy was determined by quantifying the amount of agent (or surrogate) remaining after a decontamination process, and comparing that amount to the agent (or surrogate) starting amount. The decontamination efficacy value is typically expressed in the percentage agent (or surrogate) reduction resulting from the decontamination process. The mVHP technology study evaluated the potential application of the technology to interior decontamination. In May 2005, the JPID ORD was issued specifying threshold and objective KPP for thorough decontamination efficacy of

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chemical vapor- and contact-hazards, and biological agent residual levels.[9] The JPID GD, HD, and VX contact-hazard objective values were 0.0, 0.0, and 0.00 mg/m² respectively. Since the values were reported as zeroes, mathematically statistical comparisons were not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value did not change the significant figures associated with the ORD value. The GD, HD, and VX JPID objective values used for statistical analysis were 0.05, 0.05, and 0.005 mg/m², respectively.

In spring 2005, the development of the SED prototype added the evaluation of the technology for the potential application to sensitive equipment. The potential application to sensitive equipment fell under the ORD for the JSSED program Joint Service Interior Decontamination (JSID) document. The JSSED ORD document also specified threshold and objective KPPs for thorough decontamination efficacy of chemical vapor- and contact-hazards and biological agent residual levels.[10] The JPID and JSSED ORD KPP values are listed in Table 5. The results were compared to both ORD KPPs as applicable.

Table 5. Operational requirements document (ORD) performance values.

Vapor Hazard	Starting Challenge (g/m²)	Nerve – G (mg/m³)	Nerve – V (mg/m³)	Blister – H (mg/m³)
JPID Threshold	1	<0.00087	<0.000036	<0.0058
JPID Objective	1	<0.0002	<0.000024	<0.003
JSSED Threshold	10	<0.1	<0.04	<0.1
JSSED Objective	10	<0.0001	<0.00001	<0.003
Contact Hazard	**Starting Challenge (g/m²)**	**Nerve – G (mg/m²)**	**Nerve – V (mg/m²)**	**Blister – H (mg/m²)**
JPID Threshold	1	<1.7	<0.04	<3.0
JPID Objective	1	0.0	0.00	0.0
JSSED Objective	10	<16.7	<0.78	<100
Biological Agent Reduction	**Starting Challenge (cfu/m²)**	**Bacterial Endospores (cfu/m²)**	**Vegetative Bacteria (cfu/m²)**	**Viruses (pfu/m²)**
JPID Threshold	1 x 10^8	<100	<10	<10
JSSED Objective	Not Specified	<100	<10	<10

2.7 Unique Identifier Code

Each coupon was tracked starting from placement in the containers through GC analysis using a unique identifier code. The code contained all of the information necessary to track sample placement in the decontamination chamber, vapor sample cup position, and Depot Area Air-Monitoring System (DAAMS) tube identification. The coding format was:

For Contact Tests:

Run – Dish No. – Material Type – Sampling Time – Coupon No. – Test-Replicate

For example, code "09-14-A-080-G-CON-4" was from the TGD Efficacy A run number 09. Coupon 080 was a glass sample placed in dish 14. Coupon 080 was removed at Time A and was the fourth glass replicate for the contact-hazard and residual agent measurement.

For Vapor Tests:

Run – Dish No. – Material Type – Sampling Time – Coupon No. – Test-Replicate – Vapor Cup No.

For example, code "09-13-A-078-A-VAP-4" was also from the TGD Efficacy A run number 09. Coupon 078 was an aluminum sample placed in dish 13. Coupon 078 was removed at Time A and was the fourth aluminum replicate for the vapor-hazard measurement. Further identification in the run table lists coupon 078 was analyzed in vapor cup #18.

2.8 Coupon Placement

The placement of the coupons in the decontamination chamber was tracked both by dish number and within dish position. The position information was part of the 14-character coupon identification number. Figure 6 shows a representation for the placement of 96 coupons in the decontamination chamber.

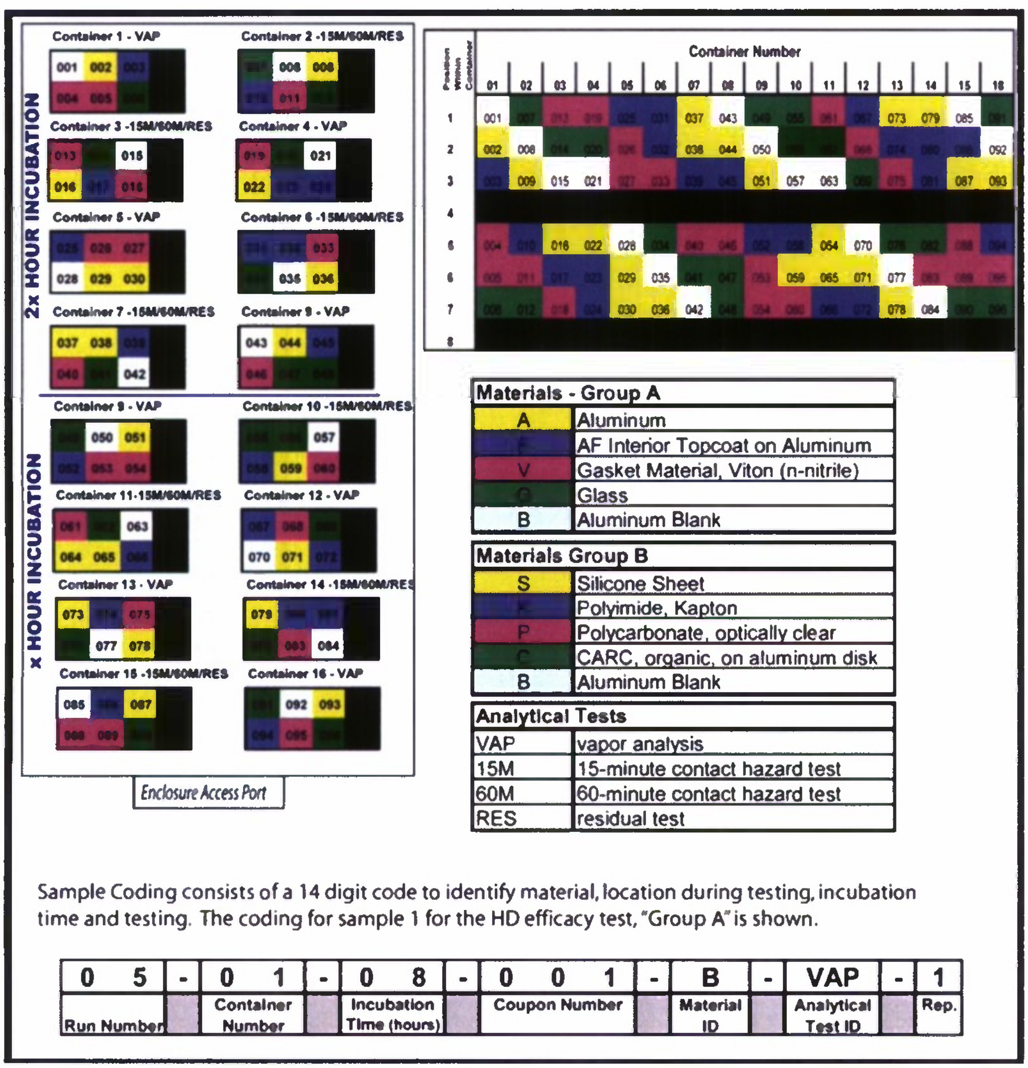


Figure 6. Efficacy test example showing coupon arrangement, placement, and coding.

2.9 mVHP Decontamination Process

Vaprox brand 35% hydrogen peroxide solution and ammonia gas were used. Two STERIS mVHP1000 custom-built systems were used to generate the mVHP fumigant. A Munters air-handler unit provided supply air for fumigant delivery, humidity control, and temperature (heating capability only) maintenance. Distilled water was used in place of the hydrogen peroxide solution for the baseline tests. The mVHP unit was manually operated by a STERIS technician, and was otherwise similar to the SED prototype, which was entirely computer controlled. Both mVHP1000 systems had data loggers. Temperature, relative humidity, and ammonia and hydrogen peroxide concentrations were recorded at least once a minute. The system default setting was once every 5 min. On occasion, data was collected at that frequency. At a minimum, the sensor data at coupon level was collected. Most runs had both the coupon level and upper box sensor results.

2.10 Decontamination Test Methods

The decontamination test methods are documented in test operating procedures (TOP) 8-2-061 Decontamination Testing.[14] An overview of the test procedures is discussed in this section.

2.10.1 Contact-Hazard and Residual-Agent Analysis

The contact test was performed by placing a pre-cut piece of silicone-latex rubber dental dam on the coupon surface for 15 min (Figure 7). The dental dam was covered with a sheet of aluminum foil (to prevent contamination of the contact weight). A 1 kg weight was placed on the aluminum foil to mimic the weight of a hand touching the surface. Fifteen minutes after the weight was applied, the weight and foil were removed, and the dental dam was placed in a 40 mL sample jar with 20 mL of ethyl acetate extractant for at least 10 min then aliquots were taken for analysis by GC-MS. Two contact test measurements were performed for each sample. The contact test required 60 min to complete. The first dental dam was in contact with the sample until 15 min elapsed; this test was referred to as the 15M test. The second dental dam was in contact with the coupon for 15 min, starting 45 min after the beginning of the 15M test, and was referred to as the 60M test (i.e., the 60M test was in contact with the coupon from 45–60 min after the contact test begins). The residual agent was measured by determining the amount of agent left on the coupon after decontamination. The coupon was placed in a 250 mL wide-mouth glass jar along with 20.0 mL of ethyl acetate. The extraction lasted for at least 10 min to remove the residual agent from the coupon. An aliquot of the extractant was analyzed by GC-MS. The results were provided to the test director in concentration (ng/µL) and corrected from extraction and injection volumes in ng. Using the methods in Section 2.12.2, these values were converted to ORD units.

2.10.2 Vapor Test Analysis

The vapor test was performed by placing the coupon in a vapor cup (Figure 8). Air was drawn across the surface, and the airflow rate and time were recorded for each tube. The effluent air was passed through a solid sorbent DAAMS tube using Tenax sorbent, where the agent was adsorbed. The HD, GD and TGD coupons were sampled at 200 mL/min for 30 min (total volume sampled/collected was 6 L). The VX coupons were sampled at 500 mL/min for 15 min (7.5 L) and used a V-to-G conversion pad to enable analysis by FPD. The collected agent was thermally desorbed from the DAAMS tube into a GC-FPD and analyzed.

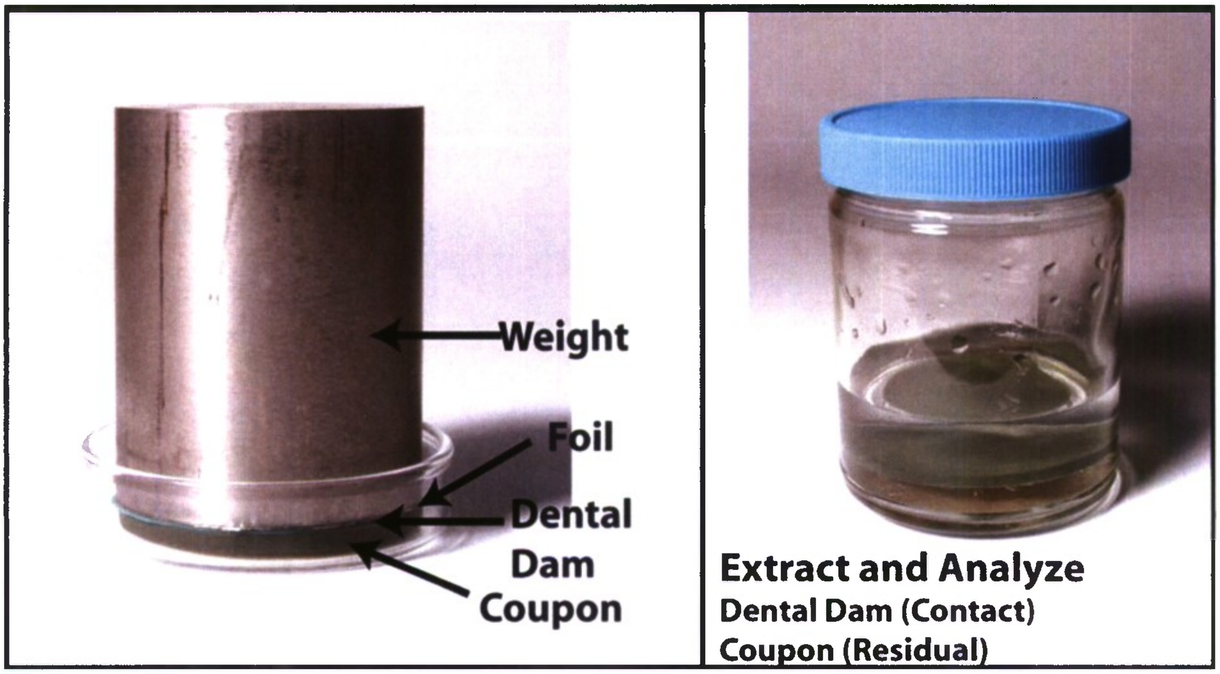


Figure 7. Contact test photograph of coupon, sampler, and weight.

The analysis of vapor test data was not as straight forward as observing a decrease in vapor concentration as a function of decontamination time. The Agent Fate program[15] specifically measured the concentration of agent vapor, resulting from the evaporation of single drops of agent from various surfaces. Figure 9 shows the vapor concentration of HD as a function of time on two different surfaces. The blue trace (diamonds) corresponds to the vapor generated from a drop of CASARM grade HD evaporating from a glass slide. The concentration may present either a constant or slightly decreasing concentration over time while the drop was evaporating. The mass of the drop decreased linearly for evaporation. When all of the agent evaporated, the vapor concentration quickly decreased to zero, as seen around the 3.5 h mark in Figure 9. This type of behavior is common to surfaces that are nonporous and do not absorb agent, such as glass, aluminum, polycarbonate, and Kapton. If the material absorbed the agent, a trend similar to the red trace was observed. The red trace (circles) corresponds to the munitions grade HD evaporation from sand. The sand quickly absorbed the agent, resulting in a much slower release of vapor. In this case, the generation of the vapor was a second-order process that took considerably longer than the nonporous case to evaporate. Materials with this type of behavior included silicone and Viton. The materials CARC and AF topcoat were slightly absorbing, and presented an intermediate behavior. The Agent Fate program demonstrated that the factors determining the vapor concentration included temperature, wind speed, drop size (surface area), drop volume, and agent-substrate interactions (e.g., absorbing or not).

These trends presented some details that must be addressed to understand the vapor test results generated from this analysis. First, this analysis acquired only one sample (tube) shortly after the decontamination was completed (one sample in the region highlighted by the green box in Figure 9). This treatment assumed that the vapor concentration was constant over time, thus the results corresponded to a worst-case treatment of the data. In the case of nonporous materials, the use of a decontaminant decreased the mass of agent. This should have resulted in a trend similar to the blue trace of Figure 9, although the time at which the vapor concentration went to zero should have decreased, as illustrated in Figure 10. Thus, after decontamination, the vapor test measurement would have likely shown a high value that did not pass ORD until full decontamination of the agent drop. The vapor test measurement did not decrease with time; it abruptly changed when the agent was fully decontaminated or evaporated.

Similarly, porous materials should have also exhibited less time for the vapor test to decrease to zero. Because this analysis acquired only one vapor sample for each coupon, the actual response of the vapor concentration vs. time, shown in Figure 10, could not be confirmed. Future experiments will implement multiple vapor samples over time to understand this response.

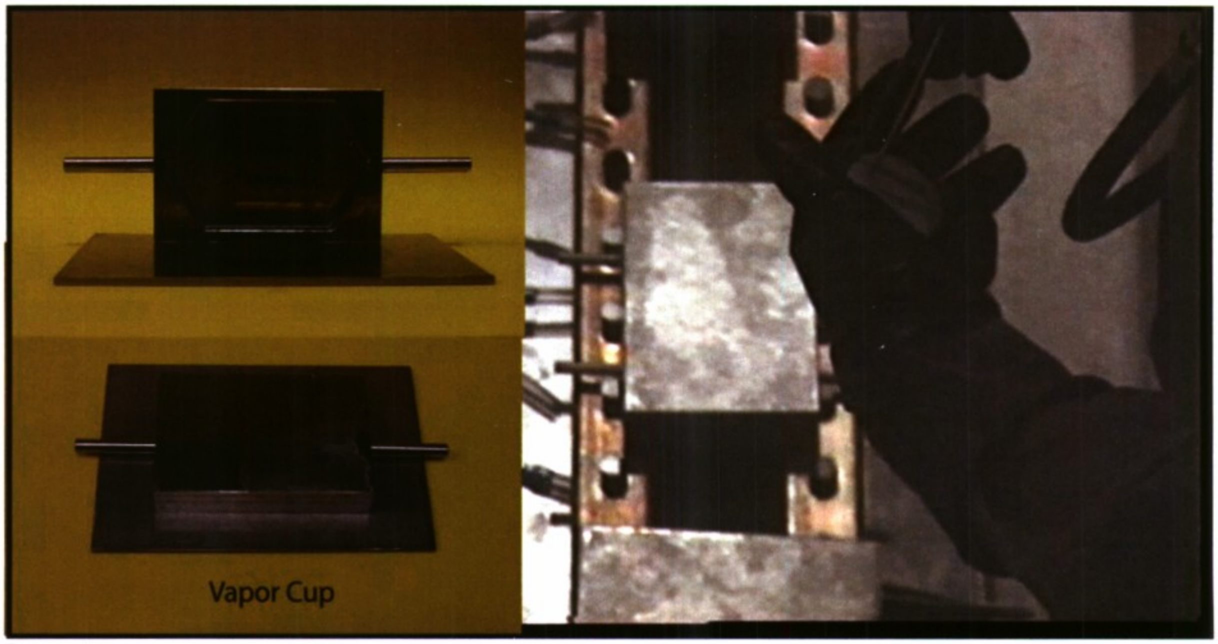


Figure 8. Vapor test cup photograph.

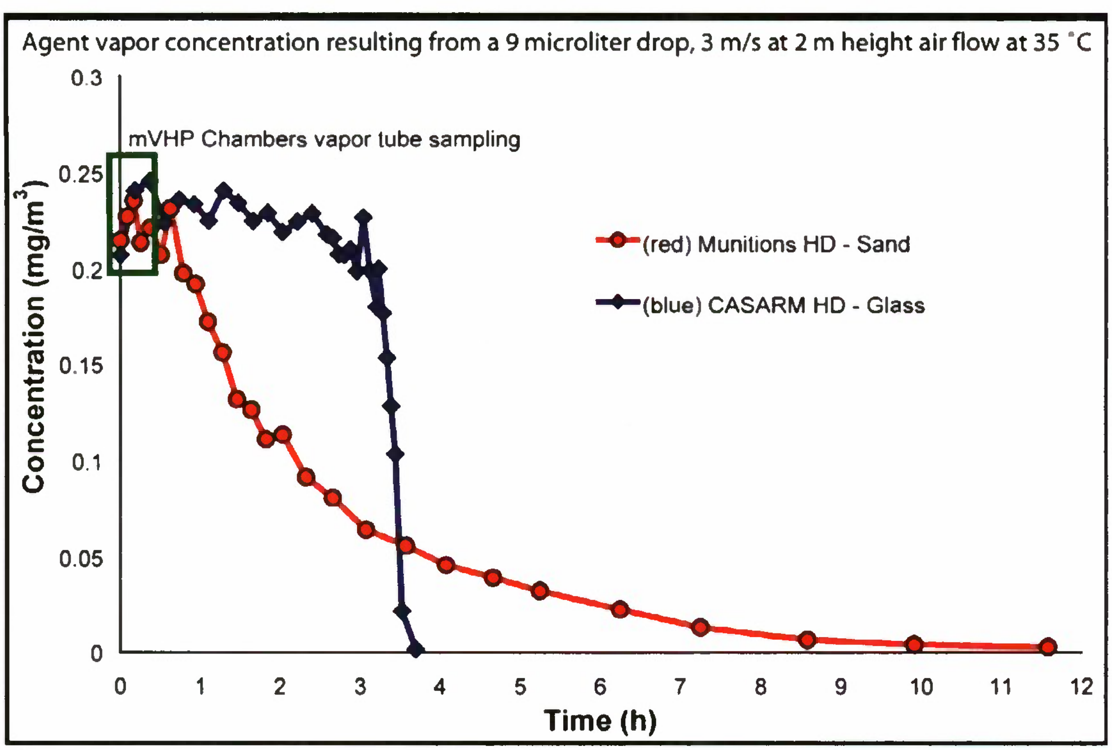


Figure 9. Vapor concentration vs. time showing evaporation only.

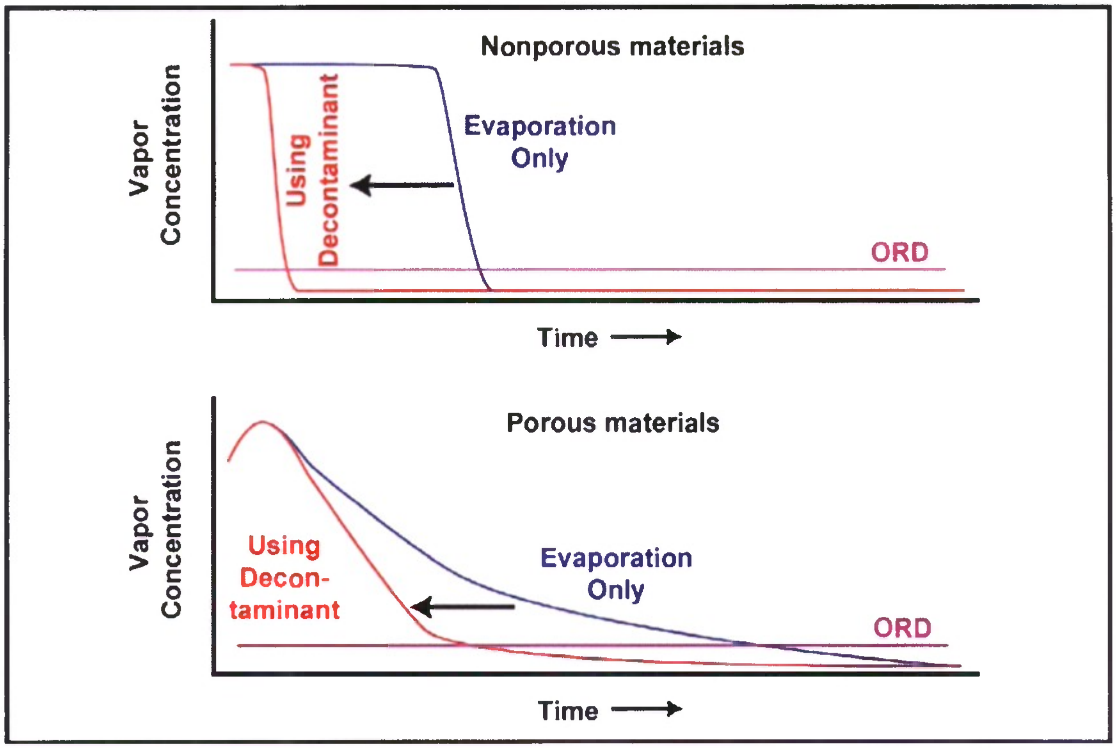


Figure 10. Vapor concentration vs. time using a decontaminant.

The abrupt change in vapor concentration (for nonporous materials) when the agent was no longer present complicated the determination of complete decontamination. The vapor test measurement consumed a test coupon for each decontamination exposure time tested. Due to the analytical load associated with these tests, this analysis used two decontamination exposure times for an agent/material combination, and acquired one vapor sample for each coupon. This resulted in three possibilities for analysis when the decontamination was complete:

(1) Both time points occurred before decontamination was complete—it was not directly possible to evaluate when the decontamination was complete.

(2) The first time point occurred before decontamination was complete and the second time point occured after—it was not possible to tell exactly when between the two points that the decontamination was completed.

(3) Both time points occurred after decontamination—decontamination took less time than the first exposure.

The use of scoping experiments was an attempt to identify the completion time for decontamination, and to determine exposure times for efficacy runs.

2.11 Analytical Procedures

2.11.1 Vapor Analysis

All vapor sample analyses were performed using a Markes Unity/Ultra TDS (thermal desorption system), an Agilent 6890N GC (gas chromatograph), an OI Analytical 5380 pFPD (pulsed flame photometric detector), and a Restek Rtx-5 SIL-MS (30 m × 0.32 mm ID × 0.25 µm df) fused silica capillary column. The vapor analysis instrument parameters are summarized in Appendix C.

A five-point calibration curve was the minimum used for all vapor analyses (Table 6). Only select samples (e.g., extraction efficiency runs) were analyzed using the extended cal 1 and extended cal 2 levels. Calibration curve construction was done using a least-squares-forcing-zero or point-to-point calculation, depending on the calibration range. The acceptance criterion for a least-squares calibration curve was a Pearson's correlation coefficient (r^2) of ≥0.98. The acceptance criterion for continuing calibration verifications (CCVs) was ≤25% relative percent difference (RPD).

Table 6. Nominal calibration masses for vapor test analysis (ng).

Agent	Low Cal	M-L Cal	Mid Cal	M-H Cal	High Cal	Extended Cal 1	Extended Cal 2
GD [1]	0.045	0.090	0.18	0.45	0.90	2.25	4.50
HD	4.5	9.00	18.0	45.0	90.0	180	
VX [2]	0.075	0.15	0.30	0.75	1.5	3.75	7.50

[1] GD parameters also apply to TGD
[2] VX was analyzed as the G analog

2.11.2 Contact Test Extraction and Analysis

All test materials were extracted with 20.0 mL of solvent. All GD, TGD, and HD extracts were performed using ethyl acetate. VX extracts were initially performed using ethyl acetate. After 07 March 2006 (runs 30 and 34), the VX extracts were performed using dichloromethane due to VX in ethyl acetate sensitivity issues.

All extract (15 min contact, 60 min contact, and residual) sample analyses were performed using an Agilent 6890N GC (gas chromatograph), an Agilent 5973 MSD (mass selective detector), and a Restek Rtx-200 (30 m × 0.32 mm ID × 0.25 µm df) fused silica capillary column or a Hewlett-Packard 5890E GC, a Hewlett-Packard 5972 Mass Selective Detector (MSD), and a Restek Rtx-200 (30 m × 0.32 mm ID × 0.25 µm df) fused silica capillary column. The extract analysis instrument parameters are summarized in Appendix C.

A five-point calibration curve was the minimum used for all extract analyses. Table 7 shows the calibration concentrations used for each agent. Only select samples were analyzed using the extended cal 1 and extended cal 2 levels. Calibration curve construction was done using a least-squares-forcing-zero or point-to-point calculation, depending on calibration range. The acceptance criterion for a least-squares calibration curve was a Pearson's correlation coefficient (r2) of ≥0.98. The acceptance criterion for CCVs was ≤25% Relative Percent Deviation (RPD).

Table 7. Nominal calibration concentrations for contact test analysis (ng/µL).

Agent	Low Cal	M-L Cal	Mid Cal	M-H Cal	High Cal	Extended Cal 1	Extended Cal 2
GD [1]	0.250	0.500	1.00	2.50	5.00	50.0	100
HD	0.200	1.000	25.00	50.00	75.0	125.0	180
VX [2]	0.005	0.025	0.05	0.250	0.50	2.5 / 5.0	125

[1] GD parameters also apply to TGD
[2] VX was analyzed as the G analog

2.12 Data Analysis Methods

2.12.1 Calibration Methods

The dynamic range of concentrations measured in this analysis covered almost six orders of magnitude, ranging from extraction efficiency runs where no decontamination occurs (possibly up to 1000 ng/μL), to decontaminated samples tested to ORD values (below 0.05 ng/μL). There was no single technique/method that could measure across this concentration range due to detector saturation or exceeding detection limits. Additionally, some detectors, such as Flame Photometric Detectors (FPDs) used for vapor analysis, have nonlinear responses at high concentrations. Thus, most of the techniques used in this report focus on mid- to low-level concentrations, as discussed in Section 2.11. Samples of high concentration were quantitatively diluted (usually by factors of 1:10 or 1:20) until they were within the range of the calibration data. However, only the contact samples could be diluted because of the volume of extractant associated with the test. The vapor analysis allowed only one run of the Depot Area Air Monitoring System (DAAMS) tube, as the entire contents of the tube was analyzed. Therefore, if a tube was outside of the calibration range, or if the Continuing Calibration Verification (CCV) failed, the tube could not be rerun.

2.12.2 Calculations and Unit Conversions

The ORD values that establish starting challenges and threshold/objective concentrations are expressed in terms of grams per square meter (g/m^2) for contact data or grams per cubic meter (g/m^3) for vapor data. The analytical techniques report concentrations in nanograms per microliter (ng/μL) for contact samples or nanograms (ng) on a tube for vapor data. The following equations demonstrate how to convert between the analytical units and the ORD units.

All tests were executed on circular coupons with a radius of 1.00 in. This corresponds to an area (A) of 0.002027 m^2. To calculate the starting challenge of the coupon, 0.0020 g of agent was delilvered to the coupon surface (e.g., four 0.5 μL drops of agent with a density of ~1.0 g/mL), equivalent to 0.0020 g agent/0.002027 m^2 = 1.0 g/m^2 starting challenge. If this coupon were placed immediately into 20.0 mL of extraction solvent, this would produce a solution with a concentration of 0.0020 g agent/ 20 mL solvent = 1 mg/mL. The conversion for solution-to-surface concentration concentration can be expressed as:

$$SurfConc = \frac{SolutionConc \times ExtractVolume}{A} \qquad \text{Equation 1}$$

For example, if a contact sample returned a concentration of 0.005 ng/μL, this would correspond to a surface concentration of (0.005 ng/μL × 20000 μL)/0.002027 m^2 = 49,333 ng/m^2 = 0.04933 mg/m^2.

The vapor data analysis was different from the contact data in that the sample was not in solution form. The agent was adsorbed on the DAAMS tube during the test. The analysis was performed by vaporizing the agent from the tube using a thermal desorption system. Rather than solution concentrations, the analytical result was mass of agent (ng) on the tube. Calculation of the vapor concentration required knowing the volume of air that was passed through the tube and the mass of agent on the tube. The volume of air was calculated from the measurement of the flow rate (mL/min) at the start and end of the measurement. These values were averaged and multiplied by the sampling time to give air volume. For example, a typical HD vapor test experiment showed flow rates of 202 and 200 mL/min at the start and end of a 15 min sample period, respectively. The air volume would be ((202+200)/2) × 15 min = 3015 mL × 1 m^3/1000000 mL = 0.003015 m^3. If the GC-FPD returned a mass of 3.5 ng for this tube, the vapor concentration would be 3.5 ng / 0.003015 m^3 = 1161 ng/m^3 = 0.001161 mg/m^3.

2.12.3 Suspect Data Points

As discussed in Section 2.11, there are criteria that must be met for a data point to be accepted, such as passing a CCV. However, there are cases where samples could not be rerun (e.g., vapor tubes). The data points were still recorded in the cases where data was not acquired within the constraints of the quality control criteria (i.e., passing linear calibration, data point was within the calibration range, and CCVs provide ≤25% RPD). The various types of failure included: detector saturation, above high calibration, below low calibration (but detected), and CCV failure. Detector saturation errors were rejected and not used in any analysis. All other errors were flagged and presented in the data tables with symbols (as shown in the next paragraph).

In the case of above high (§) and below low (¤) calibration flags, it can be assumed that the sample had a large or small concentration, respectively. However, the actual value could not be assessed due to possible nonlinearities in the detector responses, and the data point was regarded as suspect.

In the case of CCV failures (‡), the sample was usually rerun until all quality criteria was met. However, there were some instances (especially in the VX dataset) where samples could not be rerun, and the CCV failure data was all that could be analyzed. This was also true for vapor measurements as the DAAMS tubes could be analyzed once only. In these cases, the data was recovered using the CCV as a single point calibration (see U.S. Army Core of Engineers Engineering Manual 200-1-10 Section 9-4.1). While this method produced a result, the confidence in the recovered value was very low. These data points should be viewed as suspect and only provide an order of magnitude estimation of the concentration.

2.12.4 Data Treatment

Depending on the type of experiment, each sample was run with three to five replicates. The use of replicates allowed for the quantification of measurement reproducibility. Replicates were performed in the same run on the same day. In some cases there were obvious outlier data points. To prevent these statistical outliers from skewing the results, a Q test was performed at the 95% confidence level to detect and remove statistical outlier data points. Only one data point was allowed to be removed from a data set, and at least three data points had to be present to perform the Q test.

2.12.5 Data Presentation

Table 8 is an example of a data table found in this report. Each table heading includes the type of agent under test, the starting challenge, and the type of hazard test. The columns include the material being tested, the run number from which the data was generated and its associated run type, the test set type (e.g., 15M, 60M, RES for contact tests), and the exposure time (i.e., the time duration the coupon was exposed to the mVHP decontaminant). If the run type was baseline or extraction efficiency, note that NO decontaminant was used—these run types are usually highlighted in gray to emphasize that the data did not correspond to a decontaminant. In the case of samples that used the pre-wipe technology, there will be an extra column to indicate whether the sample was wiped or not.

Due to the number of tests performed, varying number of replicates, possibility of flagged data, and possibility of Q-test rejected data; the presentation of the results must include the sampling data. The column titled "Reps" includes the sampling information in the format of number of data points used to calculate the average per number of tests performed. The number of tests performed included all samples that were analyzed including rejected, flagged, or outlier data points.

The last two columns represent the analytical result, in this case, the HD contact concentration. These two columns represent the same value expressed in different units, micrograms (µg) vs. milligrams (mg). The errors presented represent one standard deviation of the data.

If a data point has been flagged, it will be indicated with the appropriate red flag, as demonstrated in Table 8. Data points can have multiple flags.

The data tables use a coloring scheme to indicate the type of decons performed on the coupons. The data points highlighted in gray indicate coupons that did not receive any decontamination (i.e., baseline and extraction efficiency data). Data points highlighted in white indicate coupons that were treated with mVHP. Yellow-highlighted data points indicate coupons that were pre-wiped and treated with mVHP. Gray highlighting also indicates the extraction efficiency data points where only the pre-wipe method was used.

Table 8. Example data table for contact test.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (µg/m²)	HD Contact Concentration (mg/m²)
Glass	19	Baseline	15M	235	4/5	1150 ± 90‡	1.150 ± 0.090‡
Glass	20	Efficacy	15M	235	4/5	150 ± 10‡	0.150 ± 0.010‡
Glass	19	Baseline	60M	235	4/5	950 ± 40‡	0.950 ± 0.040‡
Glass	20	Efficacy	60M	235	5/5	0 ± 0	0.000 ± 0.000

§ - data represents a concentration greater than the calibration range; data is suspect.
‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.
¤ - Sample concentration is less than lowest standard; data is suspect.

Most data tables are accompanied by a graph showing the contact/vapor concentration vs. the exposure time. Due to the wide dynamic range of the data between baseline data and efficacy data (in some cases greater than seven orders of magnitude), the graphs are displayed on a semi-log scale. Because a semi-log plot is used, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the corresponding table is assigned the lowest point on the y-axis (e.g., typically 1 µg/m² for contact data), so that it will be plotted in the figure. Zero exposure time corresponds to the time when the sample entered the decontamination chamber.

2.12.6 ORD Factors

Because each agent has different ORD concentrations, and there are multiple types of ORD values (e.g., threshold vs. objective and JPID vs. JSSED), the comparison between data points can be difficult and highly error prone. To circumvent this issue, a method was developed to quickly and easily identify whether the sample was decontaminated to specified ORD concentrations. The method calculates an ORD Factor as defined by:

$$\text{ORD Factor} = \frac{\text{Experimental Value}}{\text{ORD Value}} \qquad \text{Equation 2}$$

An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the specified ORD. For example, a given sample of AF topcoat with a 240 min mVHP exposure has a HD vapor concentration of 0.02369 mg/m³. The JPID threshold ORD for HD is 0.0058 mg/m³. The ORD Factor = (0.02369/0.0058) = 4.09, and from this it can be stated that this vapor concentration is a factor of 4.09 times greater than the JPID threshold concentration, and did not pass the JPID threshold ORD for this exposure time.

Table 9 shows an example of an ORD comparison table found in the results section of each hazard test. The results of all exposure times tested in efficacy run types are presented for each material. The hazard concentration is presented in ORD units (mg/m² or mg/m³) in addition to all applicable ORD Factors. All ORD values do not apply to all tests. For example, only the JSSED ORD specifies a 10 g/m² starting challenge, thus only the JSSED ORD is presented. One of the questions being assessed in this report is whether the 1 g/m² starting challenge test could be used to assess the 10 g/m² starting challenge, if the pre-wipe technology was used in combination with the mVHP technology. If this proved true, then the 1 g/m² data could be used to test against both the JPID and JSSED ORDs; thus both values are presented in the 1 g/m² tables.

Table 9. Example ORD comparison table.

Material	Exp. Time (min)	TGD Vapor Concentration (mg/m³)	JPID Thresh. Factor	JSSED Thresh. Factor	JPID Obj. Factor	JSSED Obj. Factor
AF topcoat	240	0.001041 ± 0.000503	1.20	0.01	5.21	10.41
	480	0.000181 ± 0.000127	0.21	0.00	0.90	1.81
Aluminum	120	0.006974 ± 0.000000	8.02	0.07	34.87	69.74
	298	0.000015 ± 0.000004	0.02	0.00	0.07	0.15
CARC	240	0.000097 ± 0.000014	0.11	0.00	0.49	0.97
	480	0.000038 ± 0.000037	0.04	0.00	0.19	0.38
Glass	120	0.001024 ± 0.001406	1.18	0.01	5.12	10.24
	298	0.000048 ± 0.000049	0.05	0.00	0.24	0.48
Kapton	120	0.006025 ± 0.000000§	6.93	0.06	30.13	60.25
	298	0.000058 ± 0.000059	0.07	0.00	0.29	0.58
Polycarb.	120	0.005979 ± 0.002486§	6.87	0.06	29.90	59.79
	298	0.000121 ± 0.000093	0.14	0.00	0.60	1.21
Silicone	480	0.011632 ± 0.002628	12.06	0.10	52.48	104.96
	600	0.000920 ± 0.001140	1.06	0.01	4.60	9.20
Viton	480	0.009491 ± 0.001249	10.30	0.09	44.79	89.58
	600	0.002834 ± 0.000253	3.26	0.03	14.17	28.34

§ - data represents a concentration greater than the calibration range, data is suspect.

2.12.7 JSSED ORD Comparisons

The JSSED ORD values specify a 10 g/m² starting challenge. The data presented here corresponds to a 1 g/m² starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m² to 1 g/m² for all materials tested. A 90% reduction in starting challenge, as demonstrating by comparing the 1 g/m² data compared to the JSSED ORD values, was achieved using a pre-wipe or other immediate decontamination process. If the wipe performance is validated, this 1 g/m² data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

2.13 Pre-wipe Process

The JSSED ORD test utilized a 10 g/m² challenge with and without a pre-wipe step. The pre-wipe used was a technology still in development. The wipe was a Charcoal Cloth International laminated carbon cloth (FM-50K) wetted with HFE-7200. Samples were contaminated and aged for 60 min using the same procedure as the JPID 1 g/m² challenge. A wipe was secured using Velcro® to the bottom of a mandrill (Figure 11). Holding the mandrill, the operator twisted the mandrill in a left (counterclockwise) and right (clockwise) pattern. A fresh wipe was used for each sample. Half of the samples were wiped before placement in the mVHP chamber. The samples remained stationary during the wipe motion.

2.14 Chemical Indicators (CI)

Chemical indicators (CIs) sensitive to vaporous hydrogen peroxide are regularly used by healthcare facilities for confirmation that the conditions required for sterilization have been achieved within a sterilizer. The CIs were used throughout the VHP/mVHP programs to verify that fumigant was delivered to key places within the interior space. Most programs used CIs during the initial engineering tests. The CIs served as a confirmation that fumigant was delivered to the coupon trays for each chamber test. Two brands of strips were used: Browne H_2O_2 Vapor Strips (model EN 867-1, lot 012222 exp. 07/2007, lot 009950, exp. 11/2005) and STERIS VHP Indicator (model NB305, lot 227519/1/A, exp. 6/1/2007). Figure 12 shows the STERIS VHP Indicator strips before and after exposure to mVHP.

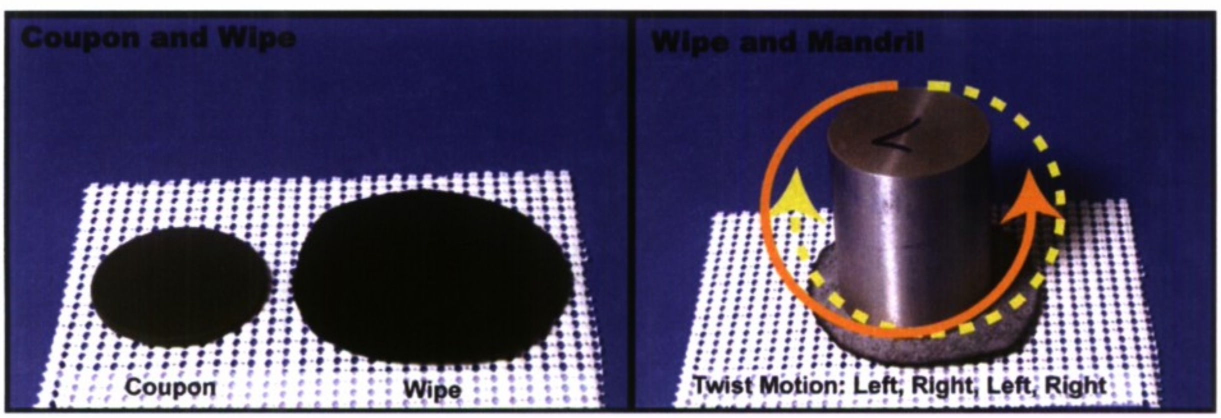


Figure 11. Pre-wipe process photograph.

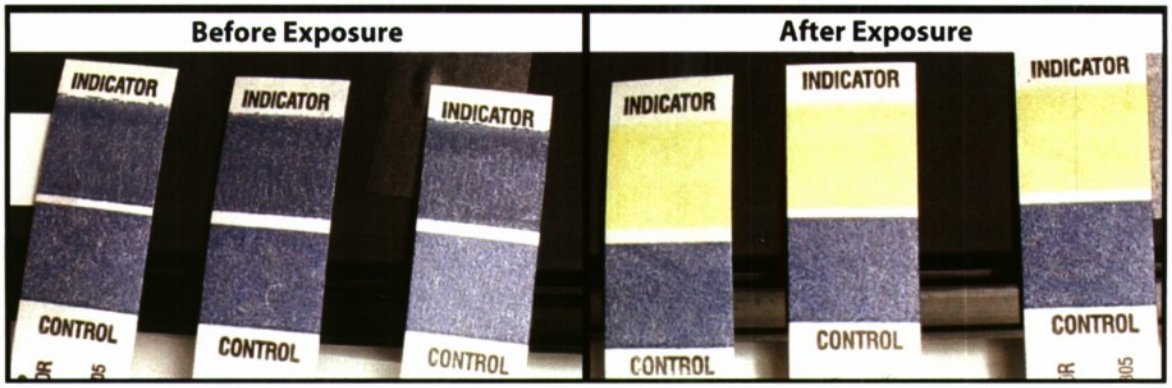


Figure 12. Chemical indicator before and after exposure to mVHP.

2.15 Types of Testing

Several types of tests were performed as part of this program. Figure 13 shows the life cycle of a coupon through these testing scenarios.

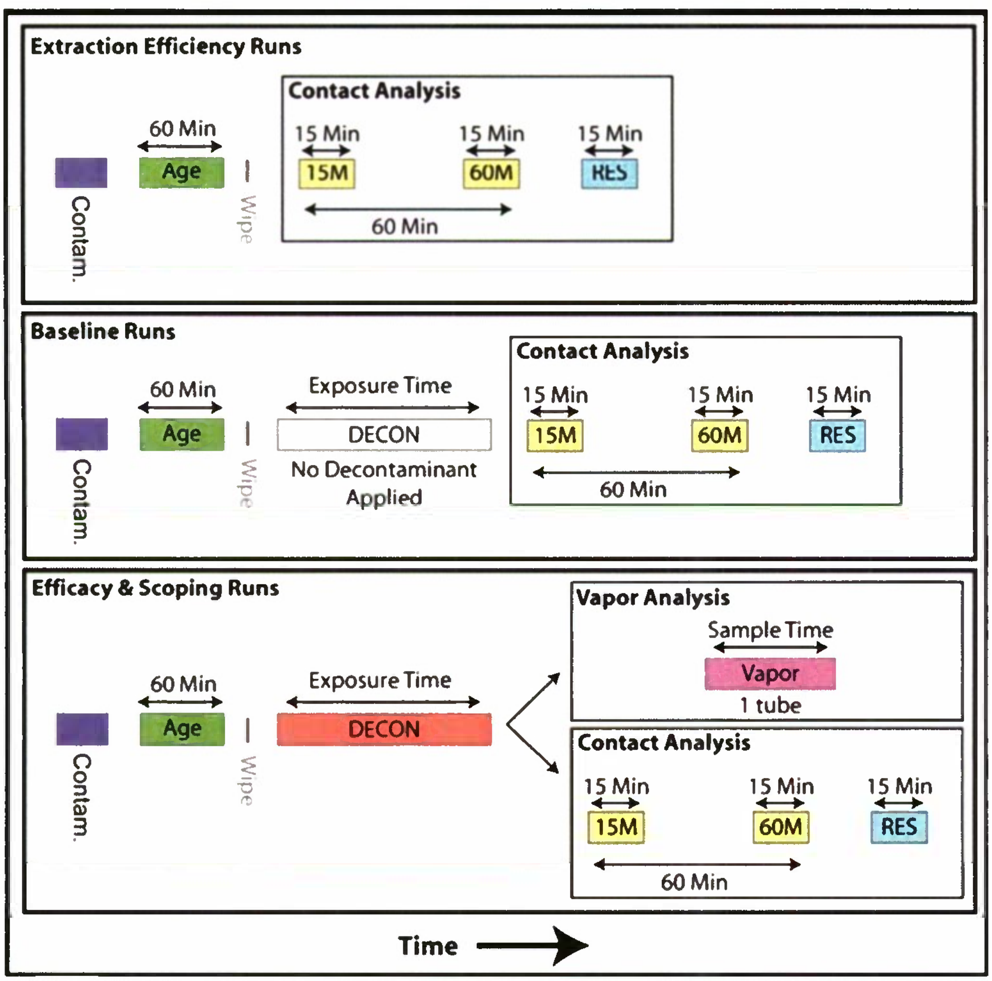


Figure 13. Coupon life cycle.

Engineering Test: The engineering test was conducted to verify that the mVHP system can achieve and maintain the target 500 ppm VHP and 30 ppm NH3 concentrations for 10 h. Tupperware containers were loaded onto the stainless steel table to mimic the test configuration. Each container had at least one chemical indicator strip to verify that fumigant contacted the inside area. The results of the engineering test are documented in the chemical agent result report.

Chemical Agent "Ambient" Baseline Tests: The ambient baseline tests were conducted with chemical agent-contaminated coupons in the chamber. The ambient baseline test was a static test that did not use any of features of the STERIS mVHP process: warm air, humidity control, airflow, hydrogen peroxide, and ammonia. The ambient baseline provided information regarding agent weathering from the coupon. Water was used in place of the hydrogen peroxide for the mVHP1000 units (i.e., decontaminant is not used) for the baseline tests.

Chemical Agent "Warm" Baseline Tests: The warm baseline tests were conducted with chemical agent-contaminated coupons in the chamber. Air was passed over the coupons for the duration of the test. The decontamination chamber's temperature and relative humidity were maintained at conditions similar to the efficacy testing. The baseline provided information regarding the impact of warm-air flow on agent removal from the coupon surface. Water was used in place of the hydrogen peroxide for the mVHP1000 units (i.e., decontaminant is not used) for the baseline tests.

Chemical Agent Scoping Tests: The scoping tests were conducted using a smaller number of contaminated coupons in the chamber. The mVHP decontaminant, airflow, temperature, and relative humidity control were used. The scoping tests were conducted for each agent to determine the sample collection times (incubation times) for the actual agent test runs.

Chemical Agent Efficacy Tests: The mVHP tests were conducted using the full set of contaminated coupon replicates. Samples were collected at two incubation times based on the scoping tests.

Chemical Agent Wipe Tests: Two tests evaluated the decontamination efficacy of coupons contaminated at a higher density. Half of the test samples were wiped prior to mVHP decontamination. The remaining samples were placed in the mVHP decontamination chamber without the pre-wipe step. Samples were collected at two incubation times similar to the efficacy tests.

3. TEST RESULTS AND DISCUSSION: ENGINEERING TEST

3.1 Test Summary

The engineering test was conducted to determine whether the mVHP generators could achieve and maintain the target 500 ppm hydrogen peroxide and 30 ppm ammonia concentrations for 10 h. Tupperware containers were loaded onto the stainless steel table to mimic the test configuration. Each container had at least one chemical indicator strip to verify that fumigant contacted the inside area of each Tupperware dish (Figure 14).

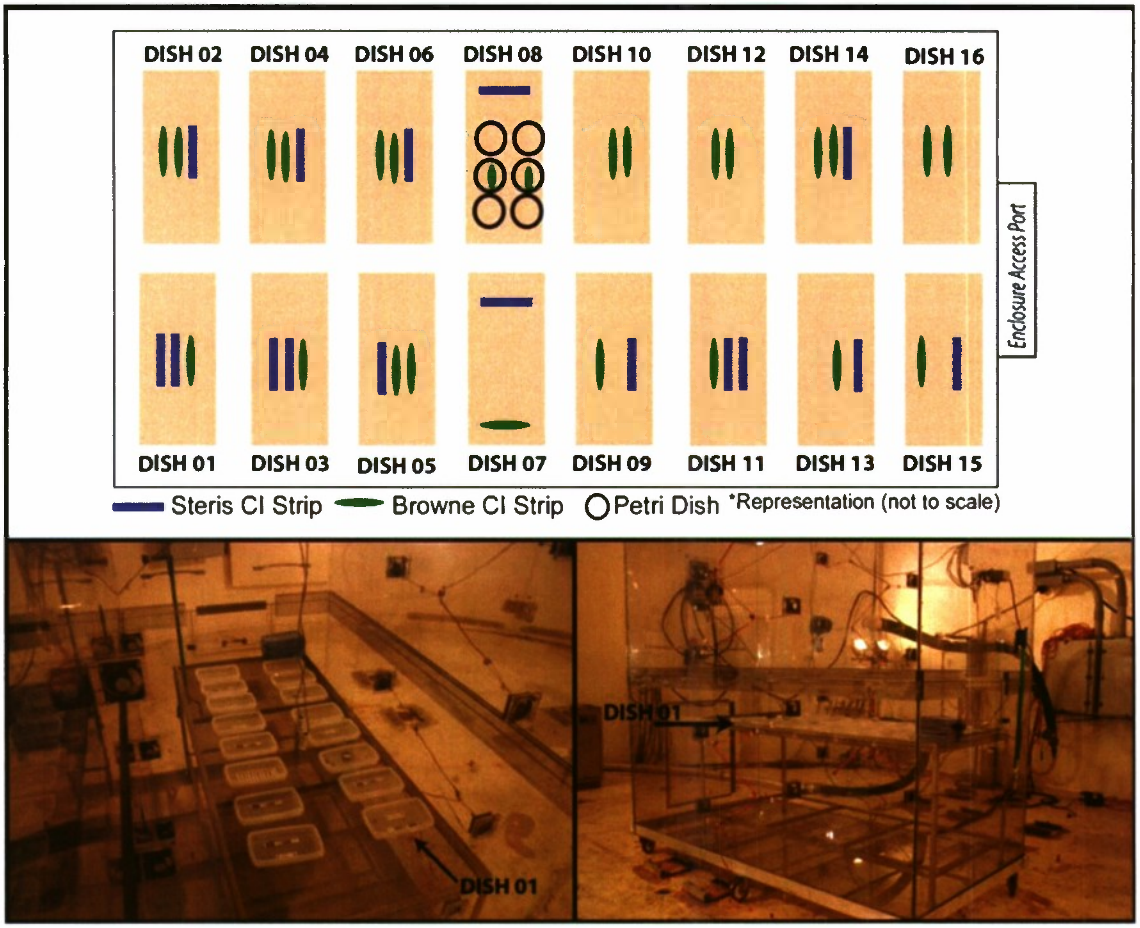


Figure 14. Engineering test dish numbers and CI locations.

3.2 Process Results

The Munters air-handler unit provided ample dehumidification capability for testing. A single mVHP1000 generator was sufficient to generate the target concentration in the chamber. Both units were used during testing to enable back-up generation in the event of generator failure. The sensor data was logged for each run. Sensor control chart examples for fumigant concentration, temperature, and relative humidity are provided in Figure 15. Green and red dashed lines were used to identify the target concentration range. The mVHP concentration in the chamber was manually controlled. A target range for a 500 ppm hydrogen peroxide and 30 ppm ammonia test was established for the sensors at the table height nearest the coupons. The concentration bounds for hydrogen peroxide and ammonia were 490–520 ppm and 28–32 ppm, respectively. The sensor data was logged and provided in Appendix B. The concentration × time (CT) value was calculated from the individual sensor values. The four phases of the mVHP decontamination process were marked.

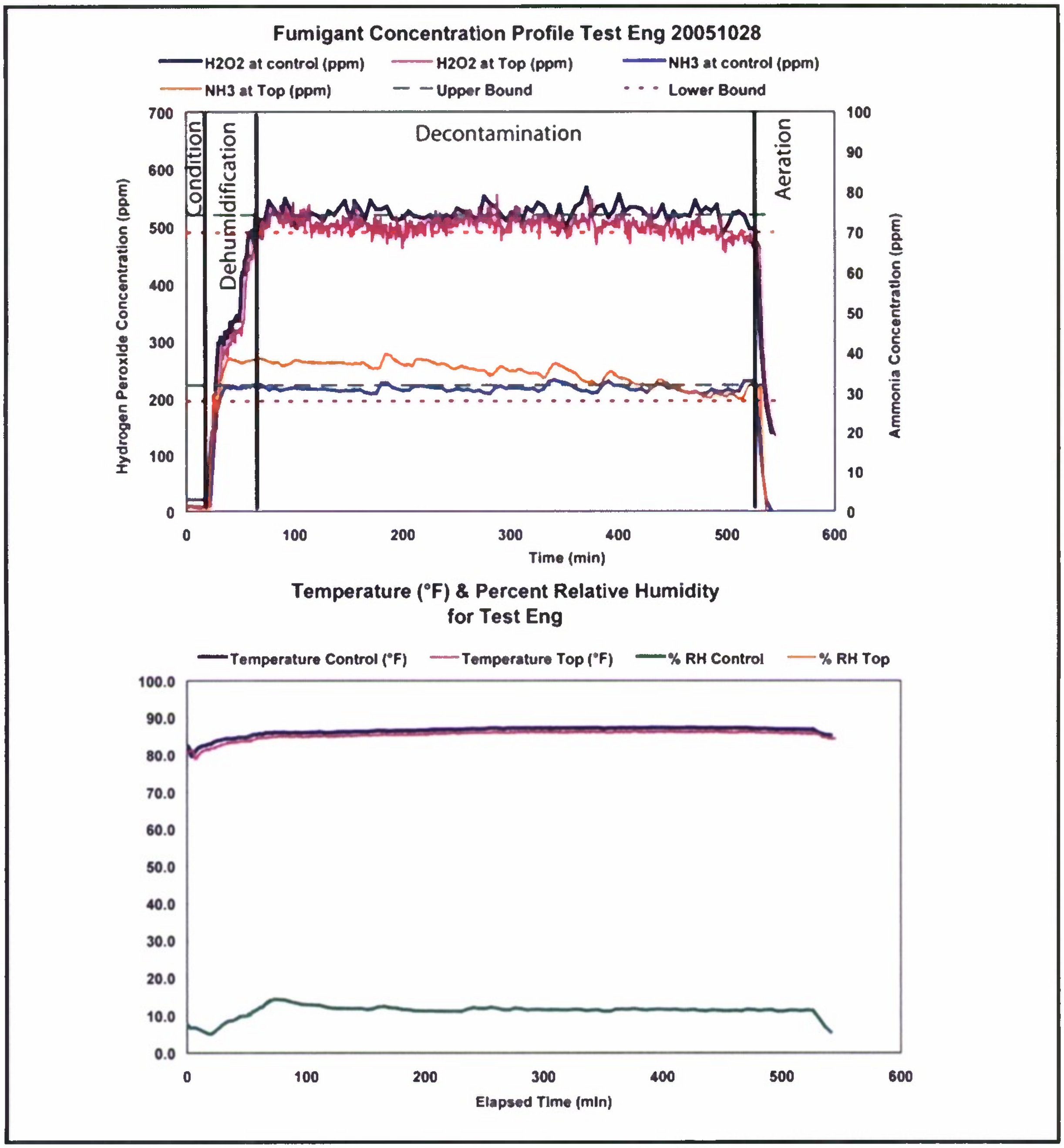


Figure 15. Engineering test control charts.

3.3 CI Results and Discussion

The CI strips were a relatively new tool evaluated during both the chamber and SED prototype test programs as a secondary verification of fumigant distribution. This approach was different than the traditional use of the CI's for sterilizer verification. The engineering test set the standard for the color change observed for a 500 ppm hydrogen peroxide and 30 ppm ammonia run. The engineering strips are shown in Figure 16. At the target concentration the STERIS brand strips changed from blue to green to bright yellow. The STERIS brand strips took longer to change color. The Browne brand strips changed from green to pink in a shorter amount of time.

Figure 16. Engineering test CI results.

3.4 Decontamination Chamber Coupon-Handling Process

The movement of coupons in and out of the decontamination chamber through the small pizza-oven door, and use of numerous DAAMS tubes resulted in some clever sample-handling techniques.

The placement of coupons on the decontamination chamber through the pizza-oven door was limited by arm length. Several extension pole-clutching tools were evaluated. These tools were well suited for short lengths. The placement of coupons further back in the chamber required additional reach length. The test personnel utilized a paint roller on an extension pole for sample placement and removal. The roller enabled a smooth movement of the Tupperware dishes along the table surface (Figure 17a).

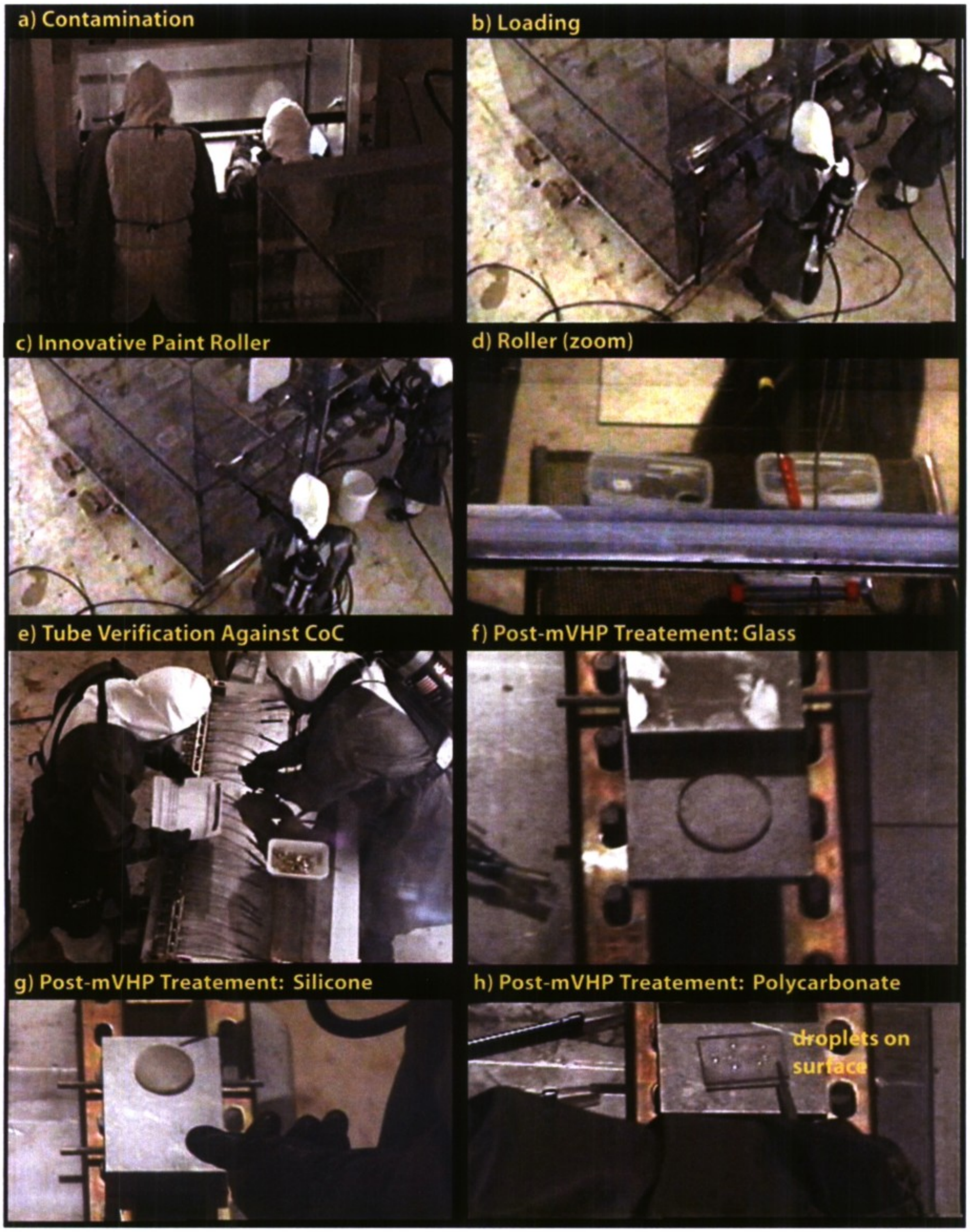


Figure 17. Chamber coupon operation photographs.

A typical efficacy run used 24 DAAMS tubes per sampling time, totaling 48 DAAMS tubes per run. The test program Chain of Custody (CoC) process tracked the DAAMS serial number to the tube location. The test personnel devised a method for tube setup using a Styrofoam block. The foam slots were numbered 1 through 24, and the tubes were preloaded for easy identification during testing. The test personnel were able to quickly set up the vapor system. During vapor sampling the tube serial numbers were compared to the CoC for final verification of placement. Refer to Appendix D.

4. MVHP PROCESS RESULTS AND SUMMARY

4.1 Test Summary

Table 10 shows the run type and settings for each experimental run. The temperature and percent relative humidity (%RH) correspond to the conditions inside the decontamination chamber during the decontamination phase. Errors listed for temperature and %RH correspond to one standard deviation of the data during the decontamination phase. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

4.2 CT Results

The exposure time and CT values for HD and TGD are presented in Table 11, and similar values for VX and GD are presented in Table 12. Each run will have one or more time points where coupons were removed from the chamber. The exposure time corresponds to the amount of time that the coupon was in the decontamination chamber, and the corresponding CT values are shown for each exposure time.

4.3 Four-Phase Process

The four-phase process is marked on the control charts in Appendix B using vertical event lines. In addition, the sample placement and removal times are marked. The treatment profiles for the runs were similar to that presented in Section 3.2.

4.4 Sensitive Equipment Decontamination (SED) Prototype Cycle Time

The Lexan decontamination chamber used in this test was a replica of the SED prototype on the 463 L pallet. The decontamination chamber provided a test enclosure with a similar volume, dimensions, fumigant distribution, and inlet and outlet ports characteristic of both the STERIS modular mVHP process and the SED prototype. The SED prototype report discussed the time to complete each phase for the runs conducted during this evaluation (SED report[8], Section 3.8). The prototype was able to rapidly dehumidify and condition the interior space to the treatment concentration. The decontamination phase was dependent on the type of contamination. The time to aerate was the most variable step, ranging from a few minutes to three hours. With optimization, a biological cycle could be as short as 60 to 120 min in this prototype. The cycle time for chemical agent studies was estimated as the sum of the dehumidification, conditioning, decontamination, and aeration times.

Table 10. Run configurations.

Run	Date	Run Type	Agent	H_2O_2 Set Point (ppm)	NH_3 Set Point (ppm)	Decon Temp. (°C)	Decon %RH
18	14-Feb-06	Scoping	HD	500	30	29.1 ± 0.2	18.9 ± 1.0
19	16-Feb-06	Baseline	HD	0	0	14.7 ± 0.7	49.3 ± 1.7
20	22-Feb-06	Efficacy	HD	500	30	27.3 ± 0.1	18.6 ± 0.8
21	24-Feb-06	Efficacy	HD	500	30	27.1 ± 0.4	17.9 ± 0.5
22	22-Feb-06	Scoping	HD	500	30	21.0 ± 0.0	60.0 ± 0.0
23	27-Feb-06	Wipe	HD	500	30	27.1 ± 0.3	18.5 ± 1.6
24	01-Mar-06	Wipe	HD	500	30	27.2 ± 0.3	12.2 ± 1.6
31 (HDE)	22-Feb-06	Extr. Eff.	HD	0	0	N/A	N/A
7	08-Dec-05	Scoping	TGD	500	30	27.9 ± 0.5	19.8 ± 0.8
8	13-Dec-05	Baseline	TGD	0	0	21.6 ± 0.4	19.6 ± 1.0
9	15-Dec-05	Efficacy	TGD	500	30	27.1 ± 0.6	18.8 ± 0.8
10	20-Dec-05	Efficacy	TGD	500	30	30.4 ± 0.5	19.3 ± 1.9
11	22-Dec-05	Scoping	TGD	500	30	30.7 ± 0.3	20.3 ± 1.1
12	05-Jan-06	Wipe	TGD	500	30	29.9 ± 0.3	20.1 ± 1.4
13	02-Feb-06	Wipe	TGD	500	30	27.3 ± 0.4	18.0 ± 0.9
28	07-Feb-06	Baseline	TGD	0	0	13.7 ± 0.8	25.4 ± 1.0
32 (TGDE)	25-Jan-06	Extr. Eff.	TGD	0	0	N/A	N/A
14	10-Jan-06	Scoping	VX	500	30	27.6 ± 0.6	20.1 ± 1.3
15	12-Jan-06	Baseline	VX	0	0	15.7 ± 0.5	53.2 ± 0.7
16	23-Jan-06	Efficacy	VX	500	30	26.4 ± 0.9	19.1 ± 3.2
17	25-Jan-06	Efficacy	VX	500	30	27.4 ± 0.5	17.7 ± 1.4
34 (17R)	15-Mar-06	Efficacy	VX	500	30	27.8 ± 0.3	15.9 ± 1.4
30	27-Mar-06	Efficacy	VX	500	30	27.4 ± 0.5	14.8 ± 2.5
35 (VXE)	18-Jan-06	Extr. Eff.	VX	0	0	N/A	N/A
3	22-Nov-05	Scoping	GD	500	30	29.1 ± 0.4	14.0 ± 1.2
4	17-Nov-05	Baseline	GD	0	0	29.9 ± 1.9	11.7 ± 3.2
5	29-Nov-05	Efficacy	GD	500	30	37.2 ± 0.4	16.8 ± 1.0
33 (5a)	29-Nov-05	Baseline	GD	0	0	35.3 ± 0.3	16.8 ± 0.6
6	01-Dec-05	Efficacy	GD	500	30	30.5 ± 0.4	17.5 ± 3.0
26	03-Jan-06	Baseline	GD	0	0	21.4 ± 0.3	33.1 ± 0.1

Using the SED box averages the sum for the dehumidification, conditioning, and aeration phases, which was approximately 83 ± 51 min. The chemical agent cycle time was then approximated as the sum of the reported treatment time, plus 83 ± 51 min. The cycle time was anticipated to decrease with system optimization.

Table 11. Exposure times and CT values for HD and TGD.

Run	Type	Agent	H_2O_2 Set Point (ppm)	Set	Exposure Time min (h)	CT H_2O_2 (ppm h)	CT NH_3 (ppm h)
18	Scoping	HD	500	A B	238 (4.0) 477 (8.0)	2038 4105	119 236
19	Baseline	HD	0	A B C	56 (0.9) 239 (4.0) 480 (8.0)	0 0 0	0 0 0
20	Efficacy	HD	500	A B	235 (3.9) 476 (7.9)	2004 4089	117 233
21	Efficacy	HD	500	A B	240 (4.0) 479 (8.0)	2107 4129	121 238
22	Scoping	HD	500	A B C	235 (3.9) 240 (4.0) 479 (8.0)	2004 2107 4129	117 121 238
23	Wipe	HD	500	A B	302 (5.0) 600 (10.0)	2605 5147	148 297
24	Wipe	HD	500	A B	300 (5.0) 600 (10.0)	2642 5212	151 297
31	Extr. Eff.	HD	0	A	0 (0)	0	0
7	Scoping	TGD	500	A	241 (4.0)	2040	124
8	Baseline	TGD	0	A B C	60 (1.0) 241 (4.0) 480 (8.0)	0 0 0	0 0 0
9	Efficacy	TGD	500	A B	120 (2.0) 298 (5.0)	1014 2613	64 155
10	Efficacy	TGD	500	A B	240 (4.0) 480 (8.0)	2080 4156	121 241
11	Scoping	TGD	500	A B	239 (4.0) 480 (8.0)	1079 4210	59 242
12	Wipe	TGD	500	A B	255 (4.3) 512 (8.5)	2202 4402	128 256
13	Wipe	TGD	500	A B	304 (5.1) 600 (10.0)	2551 5099	149 301
28	Baseline	TGD	0	A	63 (1.1)	0	0

4.5 Hydrogen Peroxide Consumption

The mVHP decontamination was a four-phase process, using hydrogen peroxide during both the conditioning and decontamination phases. The SED prototype used a flow rate of 20 cfm. The SED prototype used approximately 140 to 170 g of hydrogen peroxide/h (SED report[8], Table 3.9). The SED box was limited by the exhaust system to the lower flow rate, which was not originally anticipated. The Lexan box used a 40 cfm flow rate, and the consumptions were essentially doubled. Table 13 shows the hydrogen peroxide consumption for several runs.

Table 12. Exposure times and CT values for VX and GD.

Run	Type	Agent	H_2O_2 Set Point (ppm)	Set	Exposure Time min (h)	CT H_2O_2 (ppm h)	CT NH_3 (ppm h)
14	Scoping	VX	500	A B	237 (4.0) 479 (8.0)	2065 4152	118 241
15	Baseline	VX	0	A B C	59 (1.0) 272 (4.5) 478 (8.0)	0 0 0	0 0 0
16	Efficacy	VX	500	A B	359 (6.0) 616 (10.3)	2065 5184	118 296
17	Efficacy	VX	500	A B	354 (6.0) 595 (9.9)	3071 5149	180 301
34 (17R)	Efficacy	VX	500	A B	360 (6.0) 602 (10.0)	3154 5198	183 306
30	Efficacy	VX	500	A B	360 (6.0) 600 (10.0)	3152 5175	179 299
26	Baseline	GD	0	A B C	118 (2.0) 304 (5.1) 480 (8.0)	0 0 0	0 0 0
3	Scoping	GD	500	A B	62 (1.0) 180 (3.0)	524 1525	31 90
4	Baseline	GD	0	A	477 (8.0)	0	0
33 (5a)	Baseline	GD	0	A	62 (1.0)	0	0
5	Efficacy	GD	500	A B	124 (2.1) 234 (4.0)	1176 2728	62 157
6	Efficacy	GD	500	A B	239 (4.0) 482 (8.0)	2086 4152	123 243

Table 13. SED prototype replica hydrogen peroxide consumption for 500 ppm target.

Date	Run ID	Total H_2O_2 Consumed (gm)	Injection Duration (min)	H_2O Consump. Rate (gm/h)	H_2O_2 Cons. in Decon Phase (gm)	Decon Phase Time (min)	H_2O_2 Consump Decon Phase Only (gm)	Coupon Type
11/3/05	B03	726.8	136	321	627	123	306	Bio
12/15/05	C09	2055.0	346	356	1632	299	327	TGD
12/20/05	C10	2731.4	549	299	2389	480	299	TGD
1/5/06	C12	2984.6	587	305	2510	512	294	TGD
2/2/06	C13	3705.0	619	359	3083	596	310	TGD
1/23/06	C16	3631.8	732	298	3068	622	296	VX
1/25/06	C17	3404.4	653	313	3029	586	310	VX
2/22/06	C20	2944.6	538	328	2476	476	312	HD
2/24/06	C21	2811.6	549	307	2379	486	294	HD

5. TEST RESULTS AND DISCUSSION: HD 1 g/m^2 TEST

5.1 Test Summary for HD 1 g/m^2 Starting Challenge

The mVHP testing starting challenge was approximately 1 g/m^2 applied as three 0.5 µL drops of HD from a repeater syringe. The error bars presented in the tables and figures represent one standard deviation of the data. For each of the figures the ORD values are drawn as solid lines: these values are reviewed in Table 5. Any data point above a solid line indicates that it did not meet the ORD value. For HD, the objective values of JPID and JSSED are identical, thus they are drawn as one line in each figure.

The conditions for each experimental run and exposure time are listed in Table 11 and Table 12. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

Polycarbonate presented some material incompatibilities with HD. After exposure to HD, the surface of the polycarbonate would appear "fogged" as though the HD were solvating the plastic.

5.2 Vapor Test Results for HD 1 g/m² Starting Challenge

The results of the vapor test for 1 g/m² starting challenge of HD are presented in Table 14 – Table 17 and illustrated in Figure 18 – Figure 21. Four replicate coupons for scoping runs and five replicates for efficacy runs were measured for each material, with at least two exposure times each. These results are numerically compared to the ORDs in Section 5.3. With the exception of silicone, all materials that were in both scoping and efficacy runs show acceptable reproducibility between experimental runs. The difference between the tests cannot be explained. The efficacy test was the more tightly controlled test. The scoping tests were the first tests conducted for each agent.

Table 14. HD 1 g/m² starting challenge vapor results for glass and polycarbonate.

Material	Run	Run Type	Exposure Time (min)	Reps	HD Vapor Concentration (µg/m³)	HD Vapor Concentration (mg/m³)
Glass	20	Efficacy	235	4/5	144.20 ± 21.80	0.14420 ± 0.02180
Glass	20	Efficacy	476	4/5	0.00 ± 0.00	0.00000 ± 0.00000
Polycarb.	18	Scoping	238	4/4	89.72 ± 16.37§	0.08972 ± 0.01637§
Polycarb.	20	Efficacy	235	5/5	83.21 ± 6.79	0.08321 ± 0.00679
Polycarb.	20	Efficacy	476	5/5	8.64 ± 2.27	0.00864 ± 0.00227
Polycarb.	18	Scoping	477	4/4	13.53 ± 11.31	0.01353 ± 0.01131

§ - data represents a concentration greater than the calibration range, data is suspect.

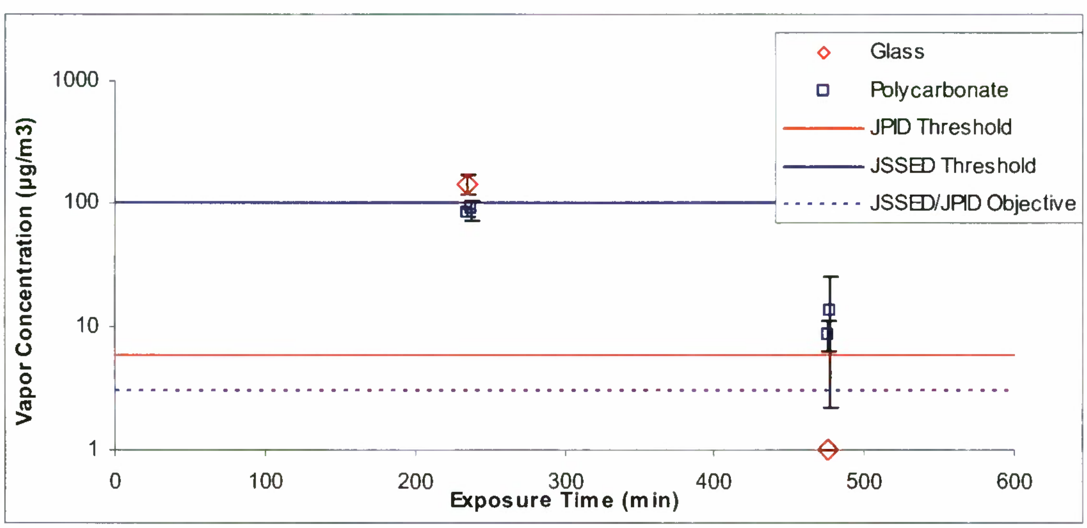


Figure 18. HD vapor concentration vs. time for glass and polycarbonate.

Table 15. HD 1 g/m² starting challenge vapor results for AF topcoat and CARC.

Material	Run	Run Type	Exposure Time (min)	Reps	HD Vapor Concentration (μg/m³)	HD Vapor Concentration (mg/m³)
AF topcoat	21	Efficacy	240	5/5	23.69 ± 25.19	0.02369 ± 0.02519
AF topcoat	21	Efficacy	479	5/5	0.00 ± 0.00	0.00000 ± 0.00000
CARC	21	Efficacy	240	5/5	0.00 ± 0.00	0.00000 ± 0.00000
CARC	21	Efficacy	479	5/5	0.00 ± 0.00	0.00000 ± 0.00000

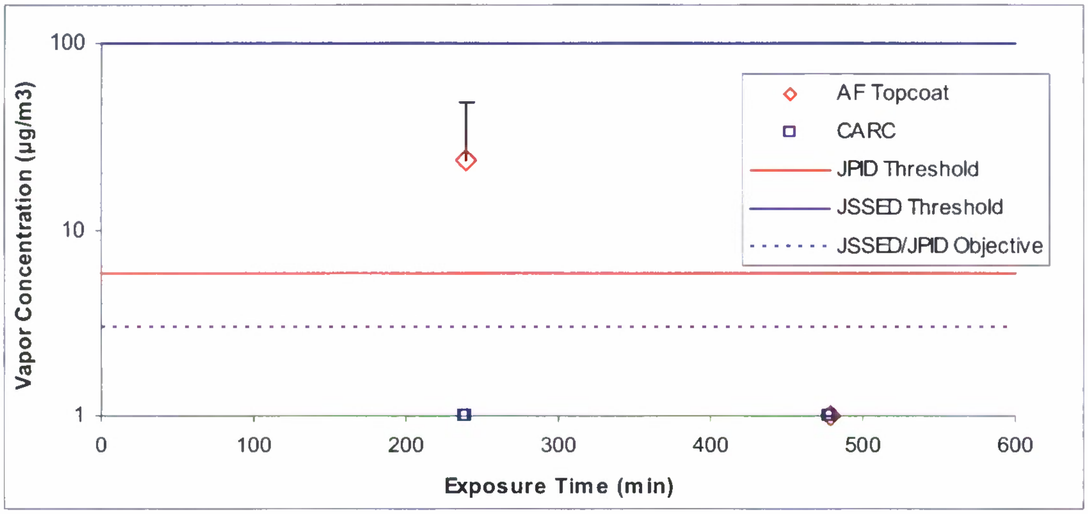


Figure 19. HD vapor concentration vs. time for AF topcoat and CARC.

Table 16. HD 1 g/m² starting challenge vapor results for silicone and Viton.

Material	Run	Run Type	Exposure Time (min)	Reps	HD Vapor Concentration (μg/m³)	HD Vapor Concentration (mg/m³)
Silicone	18	Scoping	238	3/3	37.42 ± 16.74	0.03742 ± 0.01674
Silicone	21	Efficacy	240	5/5	76.69 ± 10.60	0.07669 ± 0.01060
Silicone	18	Scoping	477	4/4	0.00 ± 0.00	0.00000 ± 0.00000
Silicone	21	Efficacy	479	5/5	52.32 ± 6.24	0.05232 ± 0.00624
Viton	21	Efficacy	240	4/5	74.91 ± 7.23	0.07491 ± 0.00723
Viton	21	Efficacy	479	5/5	35.58 ± 14.86	0.03558 ± 0.01486

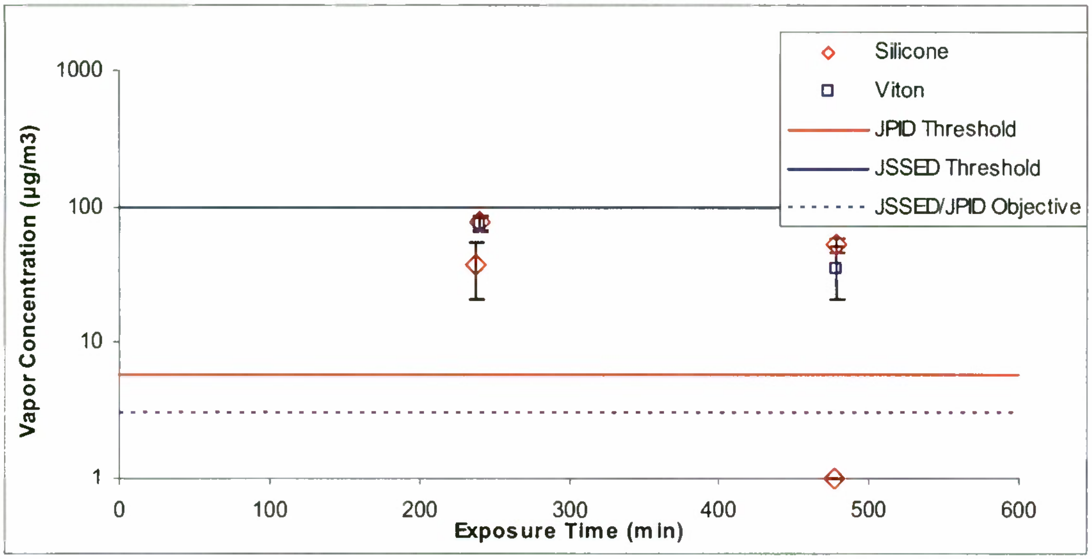


Figure 20. HD vapor concentration vs. time for silicone and Viton.

Table 17. HD 1 g/m² starting challenge vapor results for aluminum and Kapton.

Material	Run	Run Type	Exposure Time (min)	Reps	HD Vapor Concentration (μg/m³)	HD Vapor Concentration (mg/m³)
Aluminum	20	Efficacy	235	4/5	0.00 ± 0.00	0.00000 ± 0.00000
Aluminum	20	Efficacy	476	5/5	0.00 ± 0.00	0.00000 ± 0.00000
Kapton	20	Efficacy	235	5/5	0.00 ± 0.00	0.00000 ± 0.00000
Kapton	20	Efficacy	476	5/5	0.00 ± 0.00	0.00000 ± 0.00000

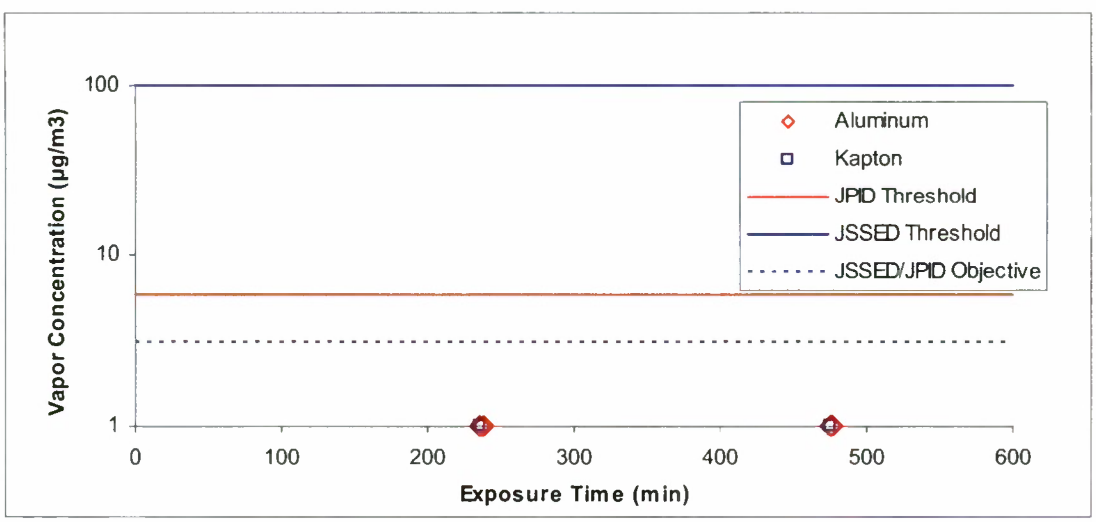


Figure 21. HD vapor concentration vs. time for aluminum and Kapton.

5.3 Vapor Test Results Compared to ORDs for HD 1 g/m² Starting Challenge

The specified HD ORD values for JPID and JSSED are provided in Table 18. The post-decontamination vapor test data for the approximately 1 g/m² HD starting challenge test is directly compared to the ORD vapor hazard values and presented in Table 19.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. For example, AF topcoat with a 240 min exposure has a vapor concentration of 0.02369 mg/m³. This vapor concentration is a factor of (0.02369 / 0.0058) = 4.09 times greater than the JPID threshold concentration and thus, did not pass the JPID threshold ORD for this exposure time. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The results for the 1 g/m² starting challenge of HD found in Table 19 are summarized in the following list.

- **AF topcoat** presents no vapor hazard between 240 and 479 min of decontamination.
- **Aluminum** presents no vapor hazard before 235 min of decontamination.
- **CARC** presents no vapor hazard before 240 min of decontamination.
- **Glass** presents no vapor hazard between 240 and 476 min of decontamination.
- **Kapton** presents no vapor hazard before 240 min of decontamination.
- **Polycarbonate** presents a vapor hazard 1.5 times the JPID threshold and 2.9 times the JSSED/JPID objective, but does pass the JSSED threshold after 476 min of decontamination.
- **Silicone** presents a vapor hazard 14.3 times the JPID threshold and 27.6 times the JSSED/JPID objective, but does pass the JSSED threshold after 479 min of decontamination.
- **Viton** presents a vapor hazard 6.13 times the JPID threshold and 11.9 times the JSSED/JPID objective, but did pass the JSSED threshold after 479 min of decontamination.

The JSSED ORD values specify a 10 g/m² starting challenge. The data presented here corresponds to a 1 g/m² starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m² to 1 g/m² for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m² data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m² data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 18. Vapor ORD values for HD.

ORD	Starting Challenge (g/m²)	HD Vapor Concentration	
		(µg/m³)	(mg/m³)
JPID Threshold	1	5.8	0.0058
JPID Objective	1	3	0.003
JSSED Threshold	10	100	0.100
JSSED Objective	10	3	0.003

Table 19. Vapor efficacy of mVHP on HD: 1 g/m² starting challenge.

Material	Exposure Time (min)	HD Vapor Concentration (mg/m³)	JPID Threshold Factor	JSSED Threshold Factor	JSSED/JPID Objective Factor
AF topcoat	240	0.02369 ± 0.02519	4.09	0.24	7.90
	479	0.00000 ± 0.00000	0.00	0.00	0.00
Aluminum	235	0.00000 ± 0.00000	0.00	0.00	0.00
	476	0.00000 ± 0.00000	0.00	0.00	0.00
CARC	240	0.00000 ± 0.00000	0.00	0.00	0.00
	479	0.00000 ± 0.00000	0.00	0.00	0.00
Glass	235	0.14420 ± 0.02180	24.86	1.44	48.06
	476	0.00000 ± 0.00000	0.00	0.00	0.00
Kapton	235	0.00000 ± 0.00000	0.00	0.00	0.00
	476	0.00000 ± 0.00000	0.00	0.00	0.00
Polycarbonate	235	0.08321 ± 0.00679	14.35	0.83	27.74
	476	0.00864 ± 0.00227	1.49	0.09	2.88
Silicone	240	0.07669 ± 0.01060	13.22	0.77	25.56
	479	0.05232 ± 0.00624	9.02	0.52	17.44
Viton	240	0.07491 ± 0.00723	12.92	0.74	24.66
	479	0.03558 ± 0.01486	6.13	0.36	11.86

5.4 Contact Test Results for HD 1 g/m² Starting Challenge

The results of the contact test for HD 1 g/m² starting challenge are presented in Table 20 – Table 27 and illustrated in Figure 22 – Figure 29 using semi-log plots. The contact test analysis methods are discussed in Section 2.10.1.

There were four types of runs used in the contact test analysis: baseline, extraction efficiency (ext. eff.), scoping, and efficacy (see Section 2.15). The baseline and extraction efficiency runs use no decontaminant. The baseline and extraction efficiency runs are highlighted in **gray** in Table 20 – Table 27 because they do not represent decontamination efficacy data (i.e., CT $H_2O_2 = 0$); they provide a baseline for the response for natural agent weathering at ambient conditions (i.e., no mVHP treatment). For each of the graphs, the "baseline" data includes both the baseline run and the extraction efficiency run (used for exposure time zero). In a similar fashion, the "efficacy" data presented in the graphs includes both efficacy and scoping data (if available).

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, thus producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table would report a value of zero, a value of 1 μg/m² was assigned so that the data point would be plotted on the graph. For HD, there is no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 5.5.

The extraction efficiency results are generally lower than the corresponding baseline measurements for most materials. This is contrary to what is expected as there was less time for evaporation with the extraction efficiency data, compared with the first baseline time point. It is possible that these lower numbers are the result of slight variances in the methods used by the operators (different personnel) who performed the extraction efficiency experiments.

Table 20. HD 1 g/m² starting challenge contact test results for AF topcoat.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (μg/m²)	HD Contact Concentration (mg/m²)
AF topcoat	31	Ext. Eff.	15M	0	3/4	391300 ± 37128	391.300 ± 37.128
AF topcoat	19	Baseline	15M	56	2/3	638669 ± 283221	638.669 ± 283.221
AF topcoat	19	Baseline	15M	239	3/3	278552 ± 169529	278.552 ± 169.529
AF topcoat	21	Efficacy	15M	240	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	21	Efficacy	15M	479	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	31	Ext. Eff.	60M	0	4/4	128788 ± 13869	128.788 ± 13.869
AF topcoat	19	Baseline	60M	56	3/3	198292 ± 47488	198.292 ± 47.488
AF topcoat	19	Baseline	60M	239	3/3	174931 ± 81966	174.931 ± 81.966
AF topcoat	21	Efficacy	60M	240	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	21	Efficacy	60M	479	5/5	0 ± 0	0.000 ± 0.000

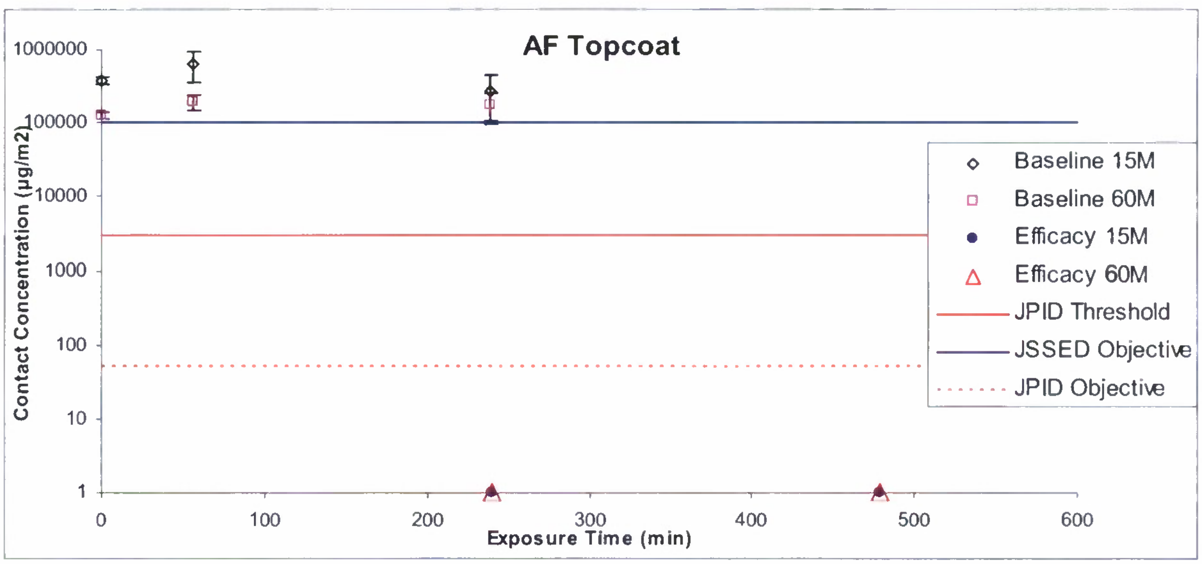


Figure 22. HD contact concentration vs. time for AF topcoat.

Table 21. HD 1 g/m² starting challenge contact test results for aluminum.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration ($\mu g/m^2$)	HD Contact Concentration (mg/m^2)
Aluminum	31	Ext. Eff.	15M	0	4/4	520575 ± 174917	520.575 ± 174.917
Aluminum	19	Baseline	15M	56	2/3	814379 ± 5957	814.379 ± 5.957
Aluminum	19	Baseline	15M	239	2/3	585124 ± 3251	585.124 ± 3.251
Aluminum	20	Efficacy	15M	235	4/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	15M	238	4/4	0 ± 0	0.000 ± 0.000
Aluminum	20	Efficacy	15M	476	5/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	15M	477	4/4	0 ± 0	0.000 ± 0.000
Aluminum	31	Ext. Eff.	60M	0	3/4	5032 ± 2433	5.032 ± 2.433
Aluminum	19	Baseline	60M	56	2/3	0 ± 0	0.000 ± 0.000
Aluminum	19	Baseline	60M	239	2/3	0 ± 0	0.000 ± 0.000
Aluminum	20	Efficacy	60M	235	5/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	60M	238	4/4	0 ± 0	0.000 ± 0.000
Aluminum	20	Efficacy	60M	476	5/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	60M	477	4/4	645 ± 926	0.645 ± 0.926

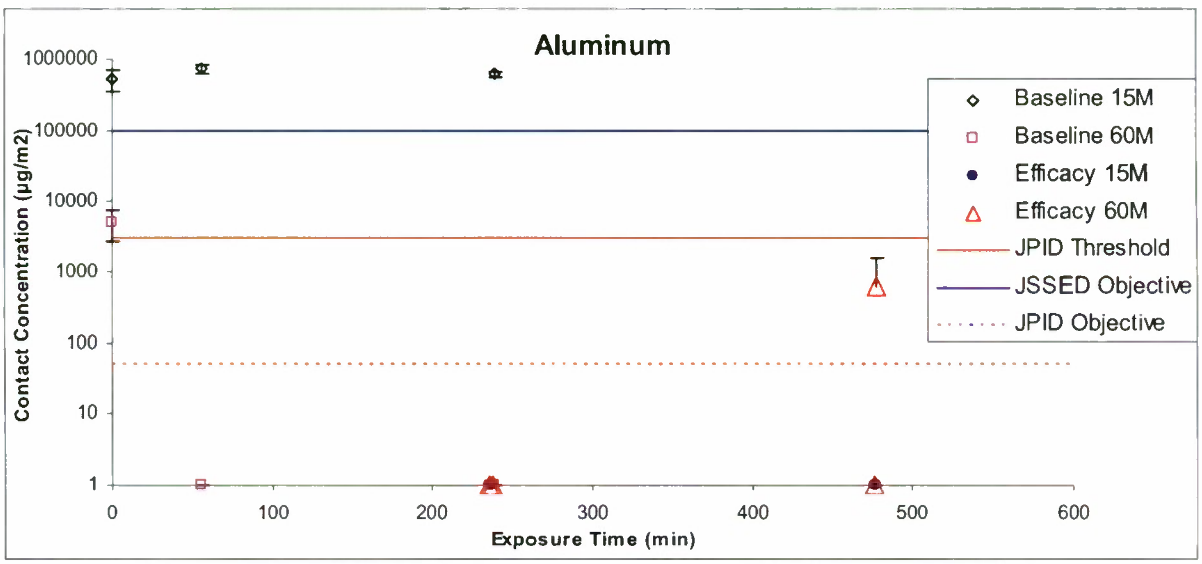


Figure 23. HD contact concentration vs. time for aluminum.

Table 22. HD 1 g/m² starting challenge contact test results for CARC.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (μg/m²)	HD Contact Concentration (mg/m²)
CARC	31	Ext. Eff.	15M	0	4/4	514425 ± 8369	514.425 ± 8.369
CARC	19	Baseline	15M	56	2/3	802615 ± 68641	802.615 ± 68.641
CARC	19	Baseline	15M	239	2/3	704118 ± 4384	704.118 ± 4.384
CARC	18	Scoping	15M	238	4/4	0 ± 0	0.000 ± 0.000
CARC	21	Efficacy	15M	240	5/5	0 ± 0	0.000 ± 0.000
CARC	18	Scoping	15M	477	4/4	0 ± 0	0.000 ± 0.000
CARC	21	Efficacy	15M	479	5/5	0 ± 0	0.000 ± 0.000
CARC	31	Ext. Eff.	60M	0	4/4	12884 ± 11256	12.884 ± 11.256
CARC	19	Baseline	60M	56	3/3	4736 ± 748	4.736 ± 0.748
CARC	19	Baseline	60M	239	3/3	3141 ± 2730	3.141 ± 2.730
CARC	18	Scoping	60M	238	4/4	0 ± 0	0.000 ± 0.000
CARC	21	Efficacy	60M	240	5/5	0 ± 0	0.000 ± 0.000
CARC	18	Scoping	60M	477	4/4	543 ± 193	0.543 ± 0.193
CARC	21	Efficacy	60M	479	5/5	0 ± 0	0.000 ± 0.000

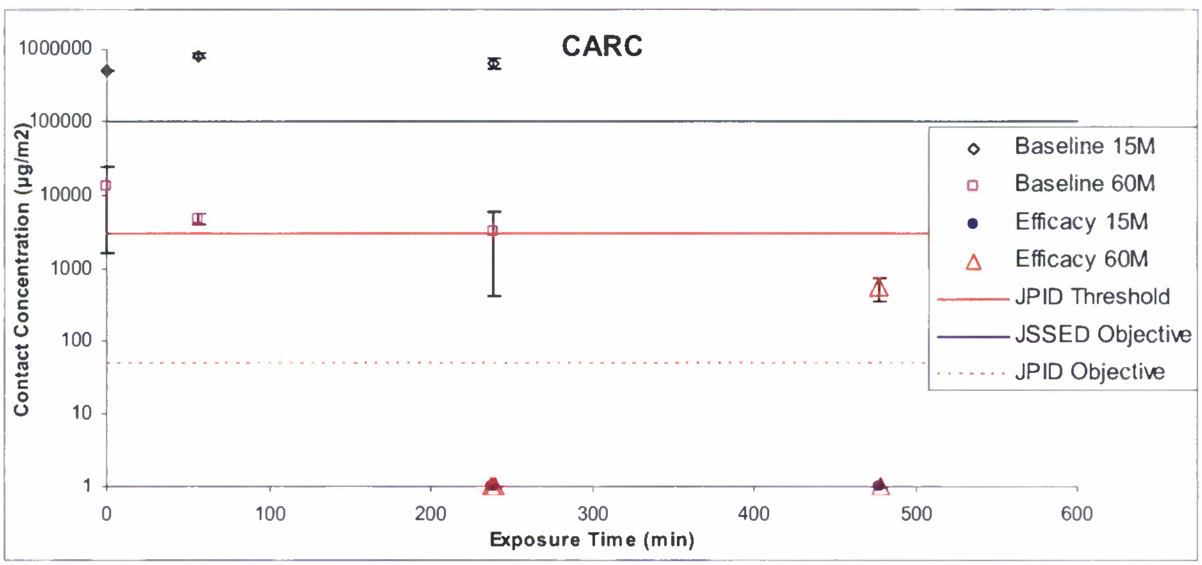


Figure 24. HD contact concentration vs. time for CARC.

Table 23. HD 1 g/m² starting challenge hazard contact results for glass.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (μg/m²)	HD Contact Concentration (mg/m²)
Glass	31	Ext. Eff.	15M	0	4/4	650530 ± 74233	650.530 ± 74.233
Glass	19	Baseline	15M	56	2/3	795534 ± 4927	795.534 ± 4.927
Glass	19	Baseline	15M	239	3/3	783311 ± 170263	783.311 ± 170.263
Glass	20	Efficacy	15M	235	4/5	0 ± 0	0.000 ± 0.000
Glass	20	Efficacy	15M	476	5/5	0 ± 0	0.000 ± 0.000
Glass	31	Ext. Eff.	60M	0	4/4	1266 ± 983	1.266 ± 0.983
Glass	19	Baseline	60M	56	3/3	0 ± 0	0.000 ± 0.000
Glass	19	Baseline	60M	239	3/3	0 ± 0	0.000 ± 0.000
Glass	20	Efficacy	60M	235	5/5	0 ± 0	0.000 ± 0.000
Glass	20	Efficacy	60M	476	5/5	0 ± 0	0.000 ± 0.000

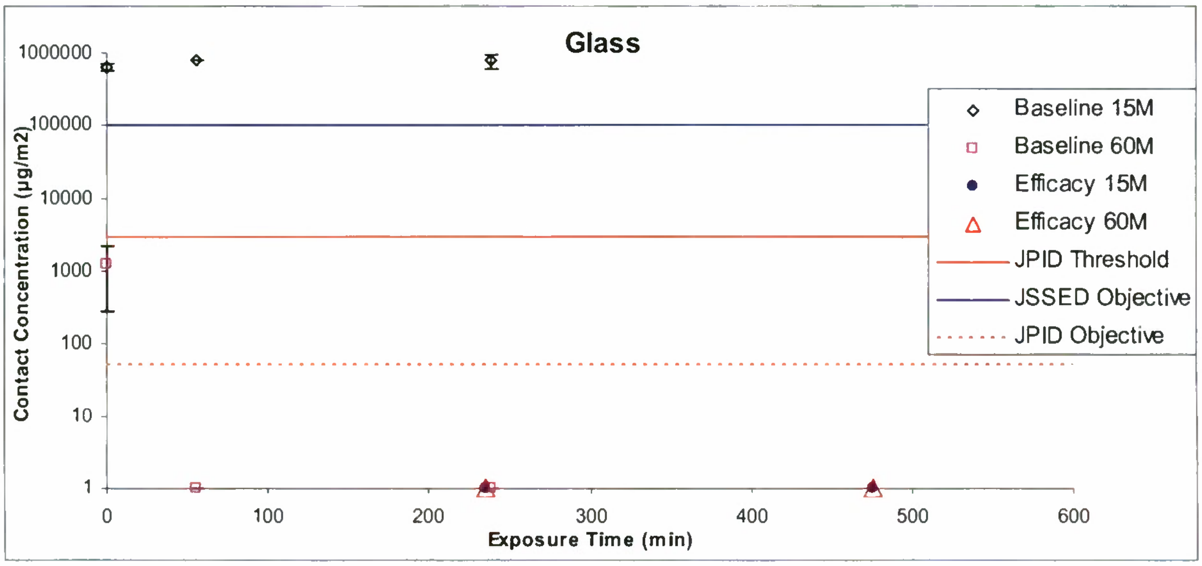


Figure 25. HD contact concentration vs. time for glass.

Table 24. HD 1 g/m² starting challenge contact test results for Kapton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (μg/m²)	HD Contact Concentration (mg/m²)
Kapton	31	Ext. Eff.	15M	0	4/4	316785 ± 189439	316.785 ± 189.439
Kapton	19	Baseline	15M	56	3/3	615418 ± 232256	615.418 ± 232.256
Kapton	19	Baseline	15M	239	3/3	310618 ± 127098	310.618 ± 127.098
Kapton	20	Efficacy	15M	235	5/5	0 ± 0	0.000 ± 0.000
Kapton	20	Efficacy	15M	476	5/5	0 ± 0	0.000 ± 0.000
Kapton	31	Ext. Eff.	60M	0	4/4	286538 ± 115279	286.538 ± 115.279
Kapton	19	Baseline	60M	56	3/3	288562 ± 54643	288.562 ± 54.643
Kapton	19	Baseline	60M	239	3/3	194891 ± 220266	194.891 ± 220.266
Kapton	20	Efficacy	60M	235	5/5	0 ± 0	0.000 ± 0.000
Kapton	20	Efficacy	60M	476	5/5	0 ± 0	0.000 ± 0.000

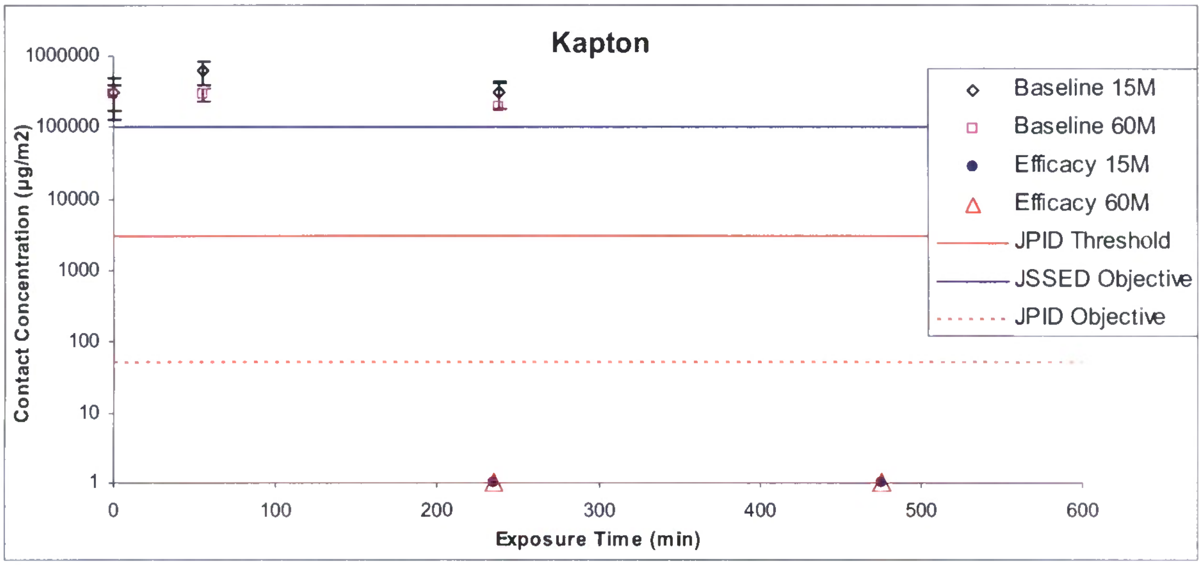


Figure 26. HD contact concentration vs. time for Kapton.

Table 25. HD 1 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (µg/m²)	HD Contact Concentration (mg/m²)
Polycarb.	31	Ext. Eff.	15M	0	4/4	79759 ± 11251	79.759 ± 11.251
Polycarb.	19	Baseline	15M	56	3/3	217577 ± 123096	217.577 ± 123.096
Polycarb.	19	Baseline	15M	239	3/3	170637 ± 47298	170.637 ± 47.298
Polycarb.	20	Efficacy	15M	235	4/5	0 ± 0	0.000 ± 0.000
Polycarb.	18	Scoping	15M	238	3/4	2110 ± 76	2.110 ± 0.076
Polycarb.	20	Efficacy	15M	476	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	18	Scoping	15M	477	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	31	Ext. Eff.	60M	0	4/4	151512 ± 20733	151.512 ± 20.733
Polycarb.	19	Baseline	60M	56	3/3	228769 ± 114950	228.769 ± 114.950
Polycarb.	19	Baseline	60M	239	3/3	94090 ± 52145	94.090 ± 52.145
Polycarb.	20	Efficacy	60M	235	4/5	3328 ± 1512	3.328 ± 1.512
Polycarb.	18	Scoping	60M	238	4/4	4963 ± 175	4.963 ± 0.175
Polycarb.	20	Efficacy	60M	476	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	18	Scoping	60M	477	4/4	439 ± 55	0.439 ± 0.055

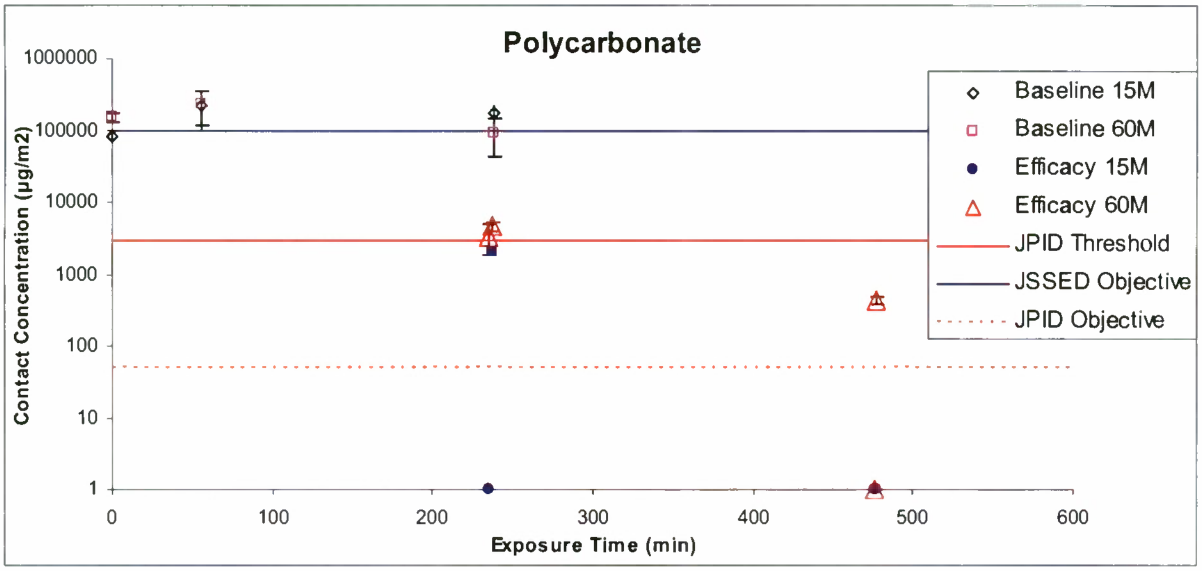


Figure 27. HD contact concentration vs. time for polycarbonate.

Table 26. HD 1 g/m² starting challenge contact test results for silicone.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (µg/m²)	HD Contact Concentration (mg/m²)
Silicone	31	Ext. Eff.	15M	0	4/4	246684 ± 170222	246.684 ± 170.222
Silicone	19	Baseline	15M	239	3/3	61563 ± 25394	61.563 ± 25.394
Silicone	19	Baseline	15M	480	3/3	19332 ± 6239	19.332 ± 6.239
Silicone	18	Scoping	15M	238	4/4	532 ± 673	0.532 ± 0.673
Silicone	21	Efficacy	15M	240	5/5	5643 ± 5216	5.643 ± 5.216
Silicone	18	Scoping	15M	477	4/4	0 ± 0	0.000 ± 0.000
Silicone	21	Efficacy	15M	479	4/5	2805 ± 474	2.805 ± 0.474
Silicone	31	Ext. Eff.	60M	0	4/4	164576 ± 19720	164.576 ± 19.720
Silicone	19	Baseline	60M	239	3/3	85258 ± 38701	85.258 ± 38.701
Silicone	19	Baseline	60M	480	3/3	127876 ± 54995	127.876 ± 54.995
Silicone	18	Scoping	60M	238	4/4	2143 ± 788	2.143 ± 0.788
Silicone	21	Efficacy	60M	240	5/5	22661 ± 3453	22.661 ± 3.453
Silicone	18	Scoping	60M	477	4/4	178 ± 210	0.178 ± 0.210
Silicone	21	Efficacy	60M	479	4/5	4261 ± 770	4.261 ± 0.770

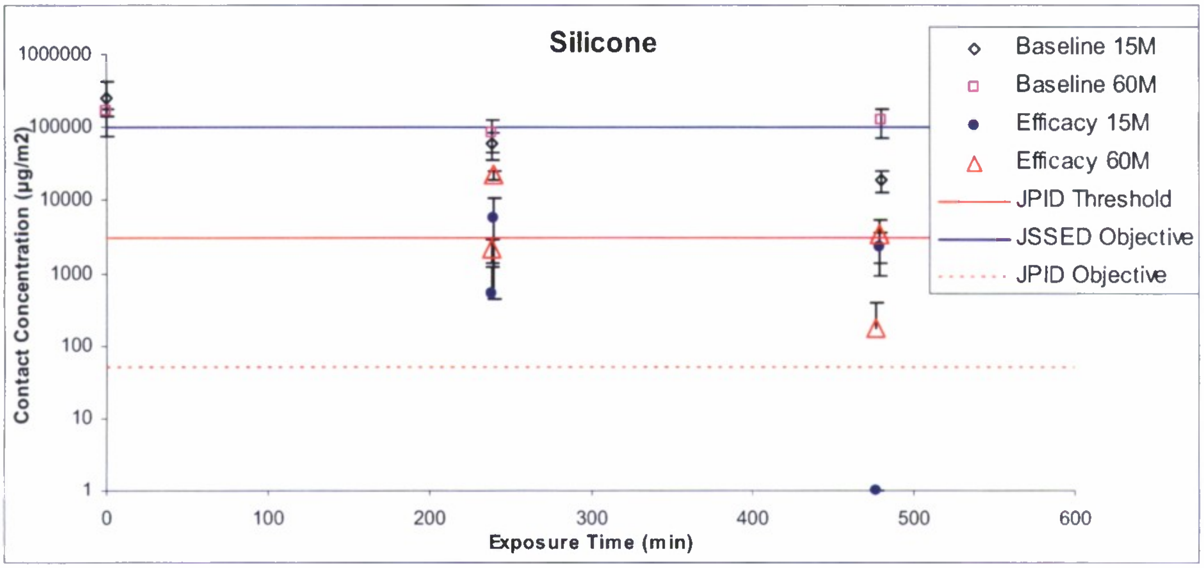


Figure 28. HD contact concentration vs. time for silicone.

Table 27. HD 1 g/m² starting challenge contact test results for Viton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (µg/m²)	HD Contact Concentration (mg/m²)
Viton	31	Ext. Eff.	15M	0	4/4	415551 ± 148918	415.551 ± 148.918
Viton	19	Baseline	15M	239	3/3	374968 ± 81398	374.968 ± 81.398
Viton	19	Baseline	15M	480	3/3	226651 ± 66737	226.651 ± 66.737
Viton	21	Efficacy	15M	240	4/5	0 ± 0	0.000 ± 0.000
Viton	21	Efficacy	15M	479	5/5	0 ± 0	0.000 ± 0.000
Viton	31	Ext. Eff.	60M	0	4/4	65695 ± 37404	65.695 ± 37.404
Viton	19	Baseline	60M	239	3/3	114973 ± 82868	114.973 ± 82.868
Viton	19	Baseline	60M	480	3/3	226718 ± 70438	226.718 ± 70.438
Viton	21	Efficacy	60M	240	4/5	0 ± 0	0.000 ± 0.000
Viton	21	Efficacy	60M	479	5/5	0 ± 0	0.000 ± 0.000

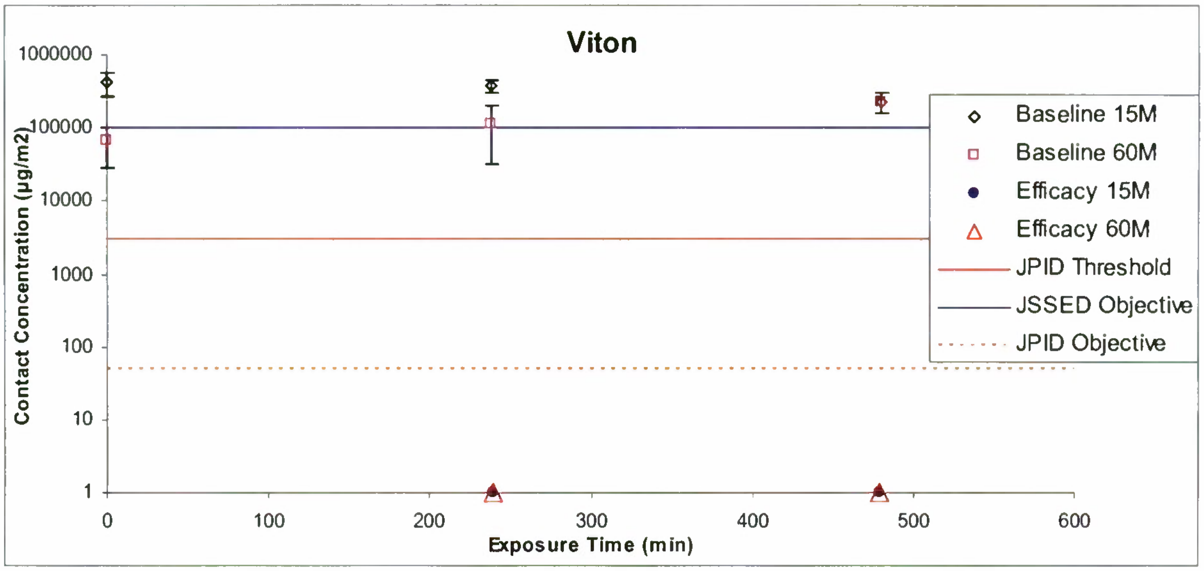


Figure 29. HD contact concentration vs. time for Viton.

In addition to the 15M and 60M test specified in the Test Operating Procedure (TOP), a residual extraction analysis was performed on each contact sample. The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, these numbers under estimated the actual residual agent that was present. The acquisition of these results was not specified in the TOP or the ORDs and, therefore, the results have no comparison to ORD values.

5.5 Contact Test Results Compared to ORDs for HD 1 g/m² Starting Challenge

The specified HD ORD values for JPID and JSSED are provided in Table 28. The post-decontamination vapor test data for the approximately 1 g/m² HD starting challenge test was directly compared to the ORD contact hazard values presented in Table 29.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The results for the 1 g/m² starting challenge of HD in Table 30 are summarized in the following list.

- **AF topcoat** presents no contact hazard before 240 min of decontamination.
- **Aluminum** presents no contact hazard before 235 min of decontamination.
- **CARC** presents no contact hazard before 240 min of decontamination.
- **Glass** presents no contact hazard before 235 min of decontamination.
- **Kapton** presents no contact hazard before 235 min of decontamination.
- **Polycarbonate** presents no contact hazard before 467 min of decontamination, although the 60M test is 1.11 times greater than the JPID threshold ORD after 235 min, and does pass JSSED ORD before 235 min of decontamination.
- **Silicone** presents a contact hazard that is 1.14 times greater than JPID threshold ORD after 479 min decontamination.

- **Viton** presents no contact hazard sometime before 240 of decontamination.

The JSSED ORD values specify a 10 g/m² starting challenge. The data presented here corresponds to a 1 g/m² starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m² to 1 g/m² for all materials tested. A 90% reduction in the starting challenge, as demonstrated by comparing the 1 g/m² data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m² data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 28. Contact ORD values for HD.

ORD	Starting Challenge (g/m²)	HD Contact Concentration	
		(µg/m²)	(mg/m²)
JPID Threshold	1	3000	3.0
JPID Objective	1	0* (50)	0.0* (0.05)
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	100000	100

* This value was set as 0.0 mg/m² in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m² (when rounded to the presented accuracy would return a result of 0.1 mg/m²) fail the JPID objective level.

Table 29. HD 1 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (µg/m²)	HD Contact Concentration (mg/m²)
AF topcoat	31	Ext. Eff.	RES	0	4/4	241 ± 21	0.241 ± 0.021
AF topcoat	19	Baseline	RES	56	3/3	301 ± 153	0.301 ± 0.153
AF topcoat	19	Baseline	RES	239	3/3	233 ± 59	0.233 ± 0.059
AF topcoat	21	Efficacy	RES	240	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	21	Efficacy	RES	479	5/5	0 ± 0	0.000 ± 0.000
Aluminum	31	Ext. Eff.	RES	0	4/4	0 ± 0	0.000 ± 0.000
Aluminum	19	Baseline	RES	56	3/3	0 ± 0	0.000 ± 0.000
Aluminum	19	Baseline	RES	239	3/3	0 ± 0	0.000 ± 0.000
Aluminum	20	Efficacy	RES	235	5/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	RES	238	3/4	0 ± 0	0.000 ± 0.000
Aluminum	20	Efficacy	RES	476	5/5	0 ± 0	0.000 ± 0.000
Aluminum	18	Scoping	RES	477	4/4	0 ± 0	0.000 ± 0.000
CARC	31	Ext. Eff.	RES	0	4/4	59 ± 17	0.059 ± 0.017
CARC	19	Baseline	RES	56	2/3	4 ± 0	0.004 ± 0.000
CARC	19	Baseline	RES	239	3/3	32 ± 31	0.032 ± 0.031
CARC	18	Scoping	RES	238	3/4	0 ± 0	0.000 ± 0.000
CARC	21	Efficacy	RES	240	5/5	0 ± 0	0.000 ± 0.000
CARC	18	Scoping	RES	477	4/4	0 ± 0	0.000 ± 0.000
CARC	21	Efficacy	RES	479	5/5	0 ± 0	0.000 ± 0.000
Glass	31	Ext. Eff.	RES	0	3/4	0 ± 0	0.000 ± 0.000
Glass	19	Baseline	RES	56	3/3	0 ± 0	0.000 ± 0.000

Table 29. HD 1 g/m² starting challenge contact test residual agent results for all materials (continued).

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Concentration (μg/m²)	HD Contact Concentration (mg/m²)
Glass	19	Baseline	RES	239	3/3	0 ± 0	0.000 ± 0.000
Glass	20	Efficacy	RES	235	5/5	0 ± 0	0.000 ± 0.000
Glass	20	Efficacy	RES	476	4/5	0 ± 1	0.000 ± 0.001
Kapton	31	Ext. Eff.	RES	0	3/4	6 ± 2	0.006 ± 0.002
Kapton	19	Baseline	RES	56	3/3	5 ± 5	0.005 ± 0.005
Kapton	19	Baseline	RES	239	3/3	0 ± 0	0.000 ± 0.000
Kapton	20	Efficacy	RES	235	4/5	0 ± 0	0.000 ± 0.000
Kapton	20	Efficacy	RES	476	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	31	Ext. Eff.	RES	0	4/4	323 ± 100	0.323 ± 0.100
Polycarb.	19	Baseline	RES	56	3/3	359 ± 46	0.359 ± 0.046
Polycarb.	19	Baseline	RES	239	3/3	295 ± 223	0.295 ± 0.223
Polycarb.	20	Efficacy	RES	235	5/5	173 ± 41	0.173 ± 0.041
Polycarb.	18	Scoping	RES	238	3/4	0 ± 0	0.000 ± 0.000
Polycarb.	20	Efficacy	RES	476	5/5	27 ± 27	0.027 ± 0.027
Polycarb.	18	Scoping	RES	477	4/4	35 ± 15	0.035 ± 0.015
Silicone	31	Ext. Eff.	RES	0	3/4	0 ± 0	0.000 ± 0.000
Silicone	19	Baseline	RES	239	3/3	349 ± 97	0.349 ± 0.097
Silicone	19	Baseline	RES	480	3/3	203 ± 176	0.203 ± 0.176
Silicone	18	Scoping	RES	238	4/4	22 ± 17	0.022 ± 0.017
Silicone	21	Efficacy	RES	240	5/5	105 ± 18	0.105 ± 0.018
Silicone	18	Scoping	RES	477	4/4	0 ± 0	0.000 ± 0.000
Silicone	21	Efficacy	RES	479	4/5	17 ± 1	0.017 ± 0.001
Viton	31	Ext. Eff.	RES	0	4/4	106 ± 24	0.106 ± 0.024
Viton	19	Baseline	RES	239	3/3	203 ± 92	0.203 ± 0.092
Viton	19	Baseline	RES	480	2/3	207 ± 4	0.207 ± 0.004
Viton	21	Efficacy	RES	240	5/5	51 ± 23	0.051 ± 0.023
Viton	21	Efficacy	RES	479	5/5	0 ± 0	0.000 ± 0.000

6. TEST RESULTS AND DISCUSSION: HD 10 g/m² TEST

6.1 Test Summary for HD 10 g/m² Starting Challenge

The 10 g/m² starting challenge loading was used to evaluate both mVHP and pre-wipe technologies. For specified samples the coupon was wiped before the mVHP decontamination. The 10 g/m² starting challenge was applied as four 4.0 μL drops from a repeater pipette. The error bars represent one standard deviation of the data. For each of the figures, the ORD values are drawn as solid lines (see Table 5 for a review). Any data point above a solid line did not meet the ORD value.

The conditions for each experimental run and exposure time are listed in Table 11 and Table 12. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

Table 30. HD 1 g/m² starting challenge contact test results compared to ORD.

Material	Exposure Time (min)	Test Set	HD Contact Concentration (mg/m²)	JPID Threshold Factor	JSSED Objective. Factor	JPID Objective. Factor
AF topcoat	240	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	479	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Aluminum	235	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	476	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
CARC	240	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	479	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Glass	235	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	476	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Kapton	235	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	476	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Polycarb.	235	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	3.328 ± 1.512	1.11	0.03	66.56
	476	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Silicone	240	15M	5.643 ± 5.216	1.88	0.06	112.86
		60M	22.661 ± 3.453	7.55	0.23	453.22
	479	15M	2.805 ± 0.474	0.94	0.03	56.10
		60M	4.261 ± 0.770	1.42	0.04	85.22
Viton	240	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	479	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00

6.2 Vapor Test Results for HD 10 g/m² Starting Challenge

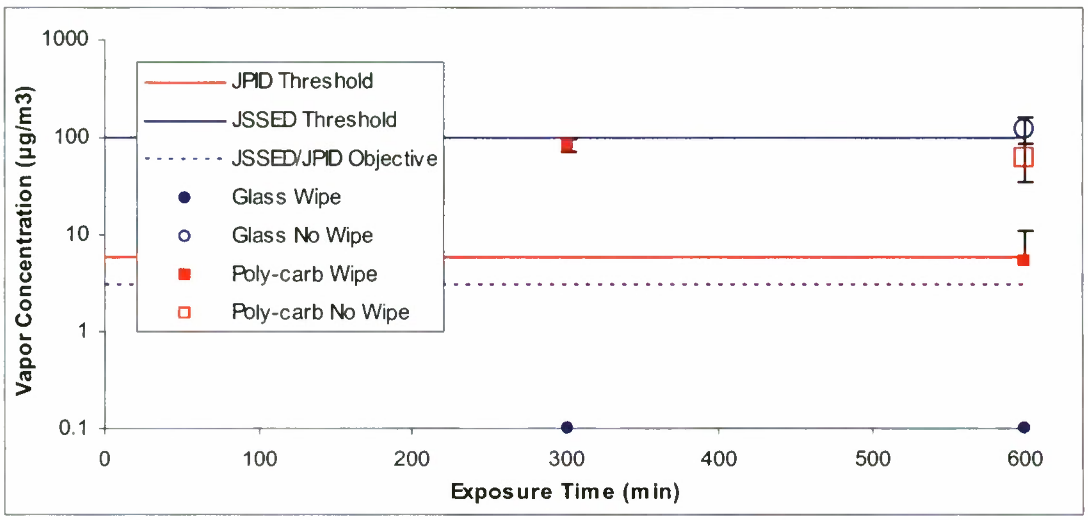
The results of the vapor test for 10 g/m² starting challenge of HD are presented in Table 31 – Table 33 and illustrated in Figure 30 – Figure 31. These results are numerically compared to the ORD in Section 6.4.

In the following table, samples that were pre-wiped will be indicated by a "Yes" value in the wiped column. Results that represent the combination of the pre-wipe method and mVHP are highlighted in gray in Table 31. Results for samples that were not pre-wiped (mVHP technology only), are not highlighted.

Table 31. HD 10 g/m² starting challenge vapor test data for glass and polycarbonate.

Material	Run	Run Type	Wiped	Exp. Time (min)	Reps	HD Vapor Concentration (µg/m³)	HD Vapor Concentration (mg/m³)
Glass	23	Wipe	No	600	5/5	122.30 ± 35.92	0.12230 ± 0.03592
			Yes	302	5/5	0.00 ± 0.00	0.00000 ± 0.00000
			Yes	600	4/5	0.00 ± 0.00	0.00000 ± 0.00000
Polycarb.	23	Wipe	No	600	5/5	61.06 ± 25.84	0.06106 ± 0.02584
			Yes	302	5/5	84.12 ± 11.75	0.08412 ± 0.01175
			Yes	600	5/5	5.37 ± 5.79	0.00537 ± 0.00579

NOTE:
Gray = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology



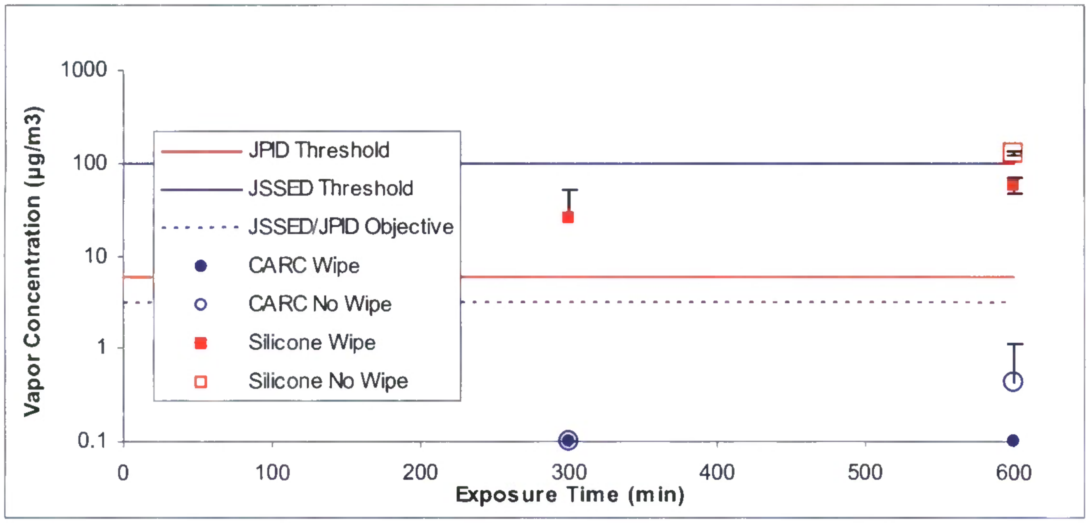
The JPID ORD level specifies a 1 g/m² starting challenge; this data corresponds to a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID.

Figure 30. HD vapor concentration vs. time for glass and polycarbonate.

Table 32. HD 10 g/m² starting challenge vapor test data for CARC and silicone.

Material	Run	Run Type	Wiped	Exp. Time (min)	Reps	HD Vapor Concentration (µg/m³)	HD Vapor Concentration (mg/m³)
CARC	24	Wipe	No	300	5/5	0.00 ± 0.00	0.00000 ± 0.00000
			No	600	5/5	0.43 ± 0.67	0.00043 ± 0.00067
			Yes	300	5/5	0.00 ± 0.00	0.00000 ± 0.00000
			Yes	600	5/5	0.00 ± 0.00	0.00000 ± 0.00000
Silicone	24	Wipe	No	600	5/5	126.61 ± 5.59	0.12661 ± 0.00559
			Yes	300	5/5	25.04 ± 27.29	0.02504 ± 0.02729
			Yes	600	5/5	58.02 ± 10.57	0.05802 ± 0.01057

NOTE:
Gray = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology



The JPID ORD level specifies a 1 g/m² starting challenge; this data corresponds to a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID.

Figure 31. HD vapor concentration vs. time for CARC and silicone.

6.3 Vapor Test Results Compared to ORDs for HD 10 g/m² Starting Challenge

The specified HD ORD values for JPID and JSSED are provided in Table 33 – Table 35. The post-decontamination vapor test data for the approximately 10 g/m² HD starting challenge was directly compared to the ORD vapor hazard values and presented in Table 34 and Table 35. Only the JSSED ORD specifies a 10 g/m² starting challenge, thus all comparisons to ORD apply only to the JSSED threshold ORD.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The comparisons are only made to the JSSED ORD for this test as the JPID ORD specifies a 1 g/m² starting challenge. The data presented here corresponds to a 10 g/m² starting challenge. The results are summarized in the following list.

- With wiping:
  - **CARC** showed no vapor hazard before 300 min of decontamination.
  - **Glass** showed no vapor hazard before 300 min of decontamination.
  - **Polycarbonate** met the JSSED objective ORD before 300 min of decontamination.
  - **Silicone** met the JSSED objective ORD before 300 min of decontamination.
- No wiping:
  - **CARC** showed no vapor hazard before 300 min of decontamination.
  - **Glass** was 1.22 times the JSSED objective ORD after 600 min of decontamination.
  - **Polycarbonate** met the JSSED objective ORD before 600 min of decontamination.
  - **Silicone** was 1.27 times the JSSED objective ORD after 600 min of decontamination.

Table 33. Vapor ORD values for HD.

ORD	Starting Challenge (g/m²)	HD Vapor Concentration	
		(μg/m³)	(mg/m³)
JPID Threshold	1	5.8	0.0058
JPID Objective	1	3	0.003
JSSED Threshold	10	100	0.100
JSSED Objective	10	3	0.003

Table 34. HD 10 g/m² starting challenge vapor test results compared to ORDs for the combination of pre-wipe and mVHP methods.

Material	Wiped	Exp. Time (min)	HD Vapor Concentration (mg/m³)	JSSED Threshold Factor	JSSED Objective Factor
CARC	Yes	300	0.00000 ± 0.00000	0.00	0.00
		600	0.00000 ± 0.00000	0.00	0.00
Glass	Yes	302	0.00000 ± 0.00000	0.00	0.00
		600	0.00000 ± 0.00000	0.00	0.00
Polycarb.	Yes	302	0.08412 ± 0.01175	0.84	28.04
		600	0.00537 ± 0.00579	0.05	1.79
Silicone	Yes	300	0.02504 ± 0.02729	0.25	8.35
		600	0.05802 ± 0.01057	0.58	19.34
NOTE: Gray = Combination of mVHP and pre-wipe technology White = Exclusively mVHP technology					

Table 35. HD 10 g/m² starting challenge vapor test results compared to ORDs for mVHP only.

Material	Wiped	Exp. Time (min)	HD Vapor Concentration (mg/m³)	JSSED Threshold Factor	JSSED Objective Factor
CARC	No	300	0.00000 ± 0.00000	0.00	0.00
		600	0.00043 ± 0.00067	0.00	0.14
Glass	No	600	0.12230 ± 0.03592	1.22	40.77
Polycarb.	No	600	0.06106 ± 0.02584	0.61	20.35
Silicone	No	600	0.12661 ± 0.00559	1.27	42.20

NOTE:
Gray = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology

6.4 Contact Test Results for HD 10 g/m² Starting Challenge

The results of the contact test for 10 g/m² starting challenge of HD are presented in Table 36 –Table 41 and illustrated in Figure 32 – Figure 36 using semi-log plots. The settings and conditions for each of these experimental runs are listed in Table 11 and Table 12.

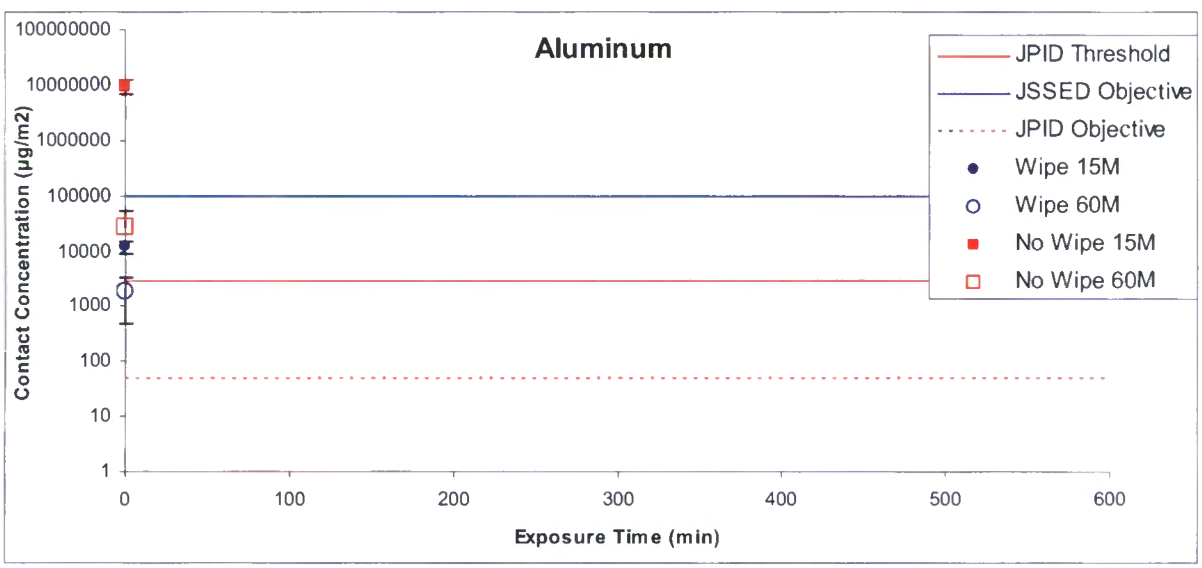
In the following tables, samples that were pre-wiped are indicated by a "Yes" value in the wiped column. Samples that were pre-wiped and exposed to mVHP are highlighted in the tables as yellow. Samples that were only pre-wiped (no mVHP used) are highlighted in gray, and samples that were not wiped (mVHP treatment only) are not highlighted.

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table reports a value of zero, a value of 1 μg/m² was assigned so that the data point would be plotted on the graph. There is no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 6.5.

Table 36. HD 10 g/m² starting challenge contact test results for aluminum.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (μg/m²)	HD Contact Hazard (mg/m²)
Aluminum	31	No	Ext. Eff.	15M	0	4/4	9,494,589 ± 2,746,927§	9494.589 ± 2746.927§
Aluminum	31	No	Ext. Eff.	60M	0	3/4	27261 ± 27388	27.261 ± 27.388
Aluminum	31	Yes	Ext. Eff.	15M	0	4/4	12102 ± 3400	12.102 ± 3.400
Aluminum	31	Yes	Ext. Eff.	60M	0	4/4	1870 ± 1401	1.870 ± 1.401

§ - data represents a concentration greater than the calibration range; data is suspect.
NOTE: Gray = Exclusively pre-wipe technology, and White = Exclusively mVHP technology.



The JPID ORD specifies a 1 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 μg/m² so that it will be plotted in the figure.

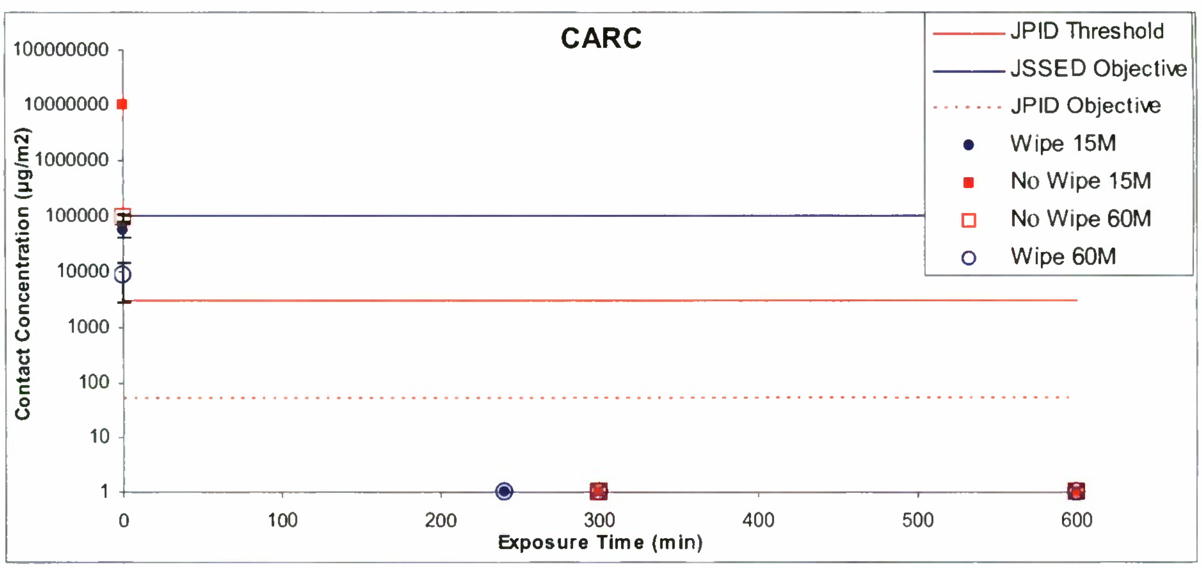
Figure 32. HD contact concentration vs. time for Aluminum (10 g/m² starting challenge).

Table 37. HD 10 g/m² starting challenge contact test results for CARC.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (μg/m²)	HD Contact Hazard (mg/m²)
CARC	31	No	Ext. Eff.	15M	0	4/4	10,318,549 ± 1,573,573§	10318.549 ± 1573.573§
CARC	24	No	Wipe	15M	300	4/5	0 ± 0	0.000 ± 0.000
CARC	24	No	Wipe	15M	600	5/5	0 ± 0	0.000 ± 0.000
CARC	31	Yes	Ext. Eff.	15M	0	4/4	57271 ± 15822	57.271 ± 15.822
CARC	22	Yes	Scoping	15M	240	4/4	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	15M	300	5/5	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	15M	600	5/5	0 ± 0	0.000 ± 0.000
CARC	31	No	Ext. Eff.	60M	0	4/4	92162 ± 14513	92.162 ± 14.513
CARC	24	No	Wipe	60M	300	4/5	0 ± 0	0.000 ± 0.000
CARC	24	No	Wipe	60M	600	5/5	0 ± 0	0.000 ± 0.000
CARC	31	Yes	Ext. Eff.	60M	0	4/4	8379 ± 5607	8.379 ± 5.607
CARC	22	Yes	Scoping	60M	240	3/4	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	60M	300	5/5	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	60M	600	5/5	0 ± 0	0.000 ± 0.000

§ - data represents a concentration greater than the calibration range; data is suspect.

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



Note that only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 μg/m² so that it will be plotted in the figure.

Figure 33. HD contact concentration vs. time for CARC (10 g/m² starting challenge).

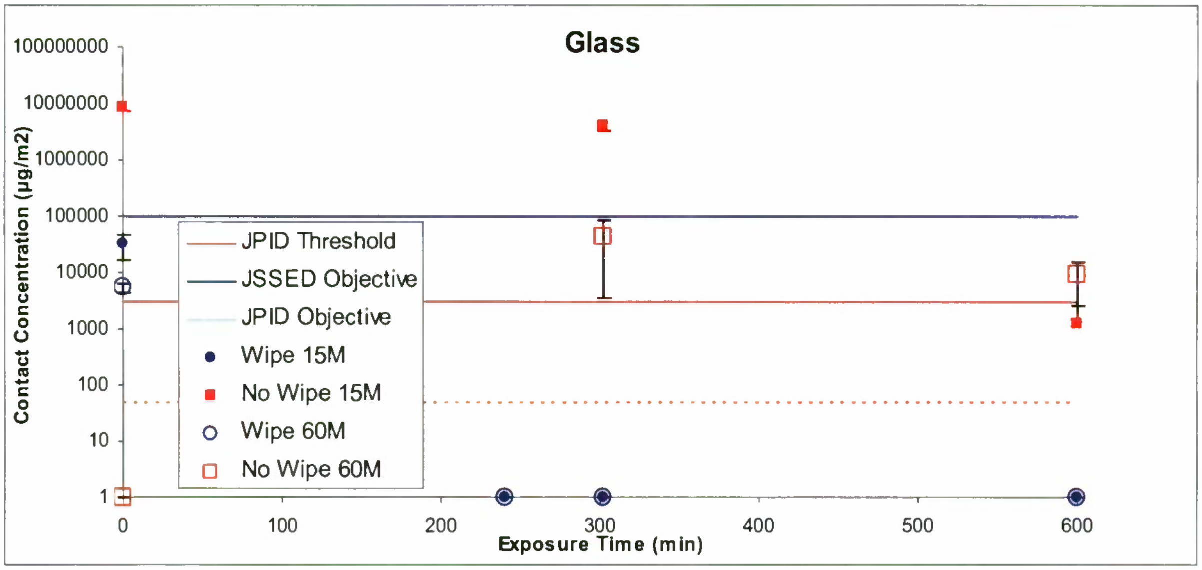
In addition to the 15M and 60M test specified in the TOP, a residual extraction analysis was performed on each contact sample. The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, the values under estimated the actual residual agent that was present. The acquisition of these results was not specified in the TOP or the ORDs and, therefore, the results have no comparison to ORD values.

Table 38. HD 10 g/m² starting challenge contact test results for glass.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (μg/m²)	HD Contact Hazard (mg/m²)
Glass	31	No	Ext. Eff.	15M	0	4/4	8660399 ± 1346524§	8660.399 ± 1346.524§
Glass	23	No	Wipe	15M	302	4/5	3957556 ± 671792	3957.556 ± 671.792
Glass	23	No	Wipe	15M	600	4/5	1209 ± 1424	1.209 ± 1.424
Glass	31	Yes	Ext. Eff.	15M	0	4/4	33163 ± 15887	33.163 ± 15.887
Glass	22	Yes	Scoping	15M	240	4/4	0 ± 0	0.000 ± 0.000
Glass	23	Yes	Wipe	15M	302	5/5	0 ± 0	0.000 ± 0.000
Glass	23	Yes	Wipe	15M	600	5/5	0 ± 0	0.000 ± 0.000
Glass	31	No	Ext. Eff.	60M	0	4/4	0 ± 0	0.000 ± 0.000
Glass	23	No	Wipe	60M	302	4/5	45137 ± 41563	45.137 ± 41.563
Glass	23	No	Wipe	60M	600	4/5	9308 ± 6777	9.308 ± 6.777
Glass	31	Yes	Ext. Eff.	60M	0	4/4	5323 ± 885	5.323 ± 0.885
Glass	22	Yes	Scoping	60M	240	4/4	0 ± 0	0.000 ± 0.000
Glass	23	Yes	Wipe	60M	302	5/5	0 ± 0	0.000 ± 0.000
Glass	23	Yes	Wipe	60M	600	5/5	0 ± 0	0.000 ± 0.000

§ - data represents a concentration greater than the calibration range; data is suspect.

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



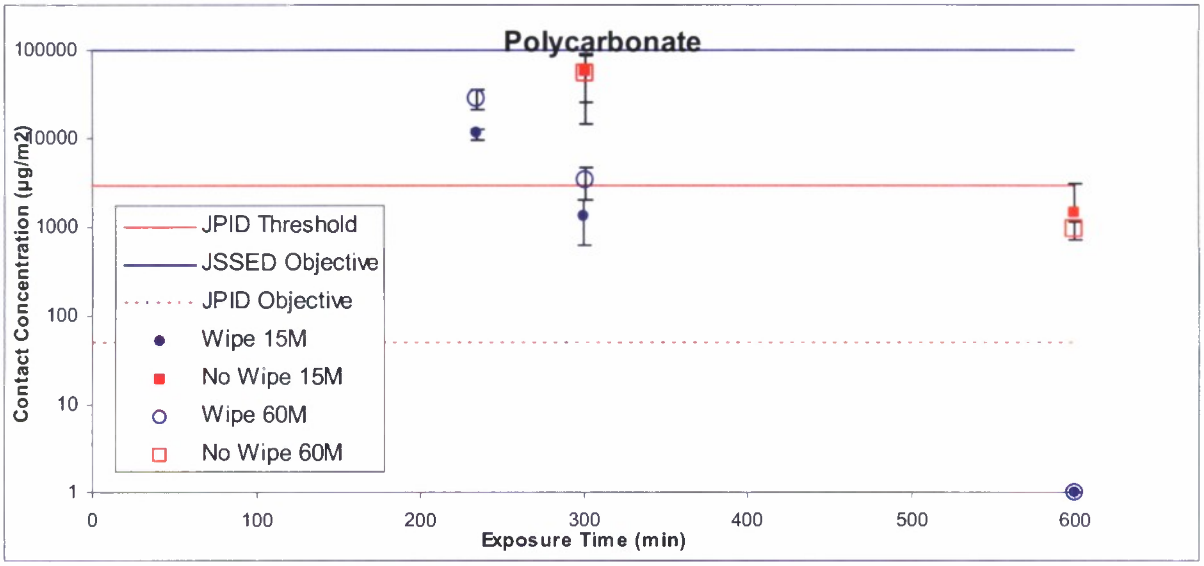
Note that only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 34. HD contact concentration vs. time for glass (10 g/m² starting challenge).

Table 39. HD 10 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (µg/m²)	HD Contact Hazard (mg/m²)
Polycarb.	23	No	Wipe	15M	302	5/5	57212 ± 31105	57.212 ± 31.105
Polycarb.	23	No	Wipe	15M	600	5/5	1445 ± 1651	1.445 ± 1.651
Polycarb.	22	Yes	Scoping	15M	235	4/4	11263 ± 1612	11.263 ± 1.612
Polycarb.	23	Yes	Wipe	15M	302	5/5	1311 ± 692	1.311 ± 0.692
Polycarb.	23	Yes	Wipe	15M	600	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	23	No	Wipe	60M	302	5/5	53312 ± 38897	53.312 ± 38.897
Polycarb.	23	No	Wipe	60M	600	4/5	937 ± 212	0.937 ± 0.212
Polycarb.	22	Yes	Scoping	60M	235	4/4	28335 ± 6725	28.335 ± 6.725
Polycarb.	23	Yes	Wipe	60M	302	5/5	3372 ± 1380	3.372 ± 1.380
Polycarb.	23	Yes	Wipe	60M	600	5/5	0 ± 0	0.000 ± 0.000

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



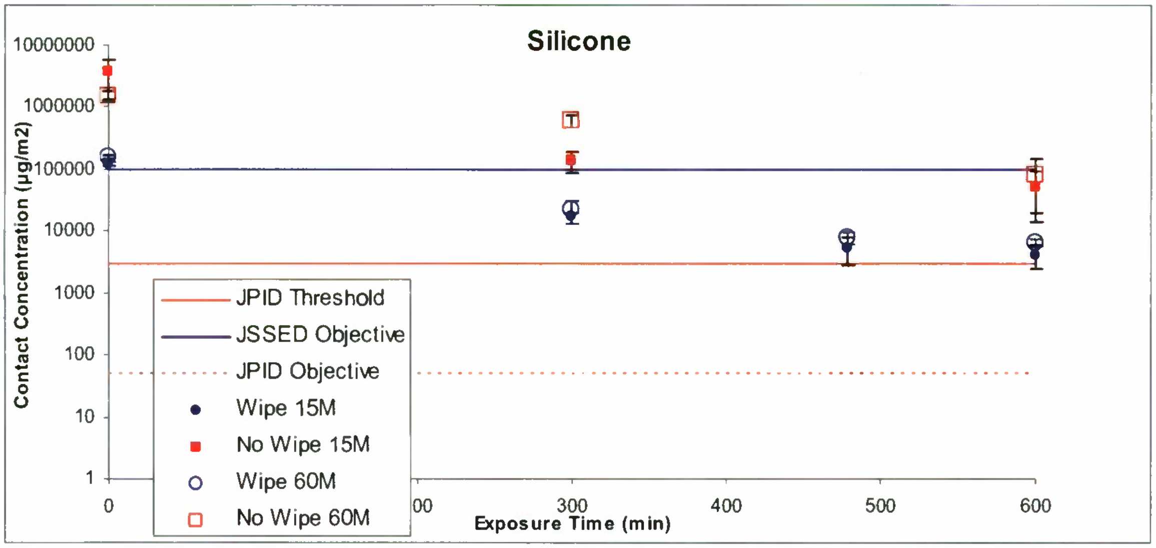
Note that only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 35. HD contact concentration vs. time for polycarbonate (10 g/m² starting challenge).

Table 40. HD 10 g/m² starting challenge contact test results for silicone.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (µg/m²)	HD Contact Hazard (mg/m²)
Silicone	24	No	Ext. Eff.	15M	0	4/4	3,740,999 ± 2,377,014	3740.999 ± 2377.014
Silicone	24	No	Wipe	15M	300	5/5	135876 ± 51295	135.876 ± 51.295
Silicone	24	No	Wipe	15M	600	5/5	50896 ± 38227	50.896 ± 38.227
Silicone	31	Yes	Ext. Eff.	15M	0	4/4	120004 ± 8130	120.004 ± 8.130
Silicone	24	Yes	Wipe	15M	300	5/5	16690 ± 3073	16.690 ± 3.073
Silicone	22	Yes	Scoping	15M	479	4/4	5361 ± 2592	5.361 ± 2.592
Silicone	24	Yes	Wipe	15M	600	5/5	4204 ± 1805	4.204 ± 1.805
Silicone	24	No	Ext. Eff.	60M	0	4/4	1,544,499 ± 280,459	1544.499 ± 280.459
Silicone	24	No	Wipe	60M	300	5/5	601401 ± 130428	601.401 ± 130.428
Silicone	24	No	Wipe	60M	600	5/5	82183 ± 62919	82.183 ± 62.919
Silicone	31	Yes	Ext. Eff.	60M	0	4/4	155779 ± 13836	155.779 ± 13.836
Silicone	24	Yes	Wipe	60M	300	5/5	21976 ± 9144	21.976 ± 9.144
Silicone	22	Yes	Scoping	60M	479	4/4	7737 ± 1811	7.737 ± 1.811
Silicone	24	Yes	Wipe	60M	600	5/5	6505 ± 975	6.505 ± 0.975

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



Note that only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 36. HD contact concentration vs. time for silicone (10 g/m² starting challenge).

Table 41. HD 10 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Wiped	Run Type	Test Set	Exp. Time (min)	Reps	HD Contact Hazard (µg/m²)	HD Contact Hazard (mg/m²)
Aluminum	31	Yes	Ext. Eff.	RES	0	3/4	0 ± 0	0.000 ± 0.000
CARC	24	No	Wipe	RES	300	5/5	2 ± 0	0.002 ± 0.000
CARC	24	No	Wipe	RES	600	5/5	2 ± 1	0.002 ± 0.001
CARC	31	Yes	Ext. Eff.	RES	0	4/4	22 ± 9	0.022 ± 0.009
CARC	22	Yes	Scoping	RES	240	4/4	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	RES	300	5/5	0 ± 0	0.000 ± 0.000
CARC	24	Yes	Wipe	RES	600	5/5	0 ± 0	0.000 ± 0.000
Glass	23	No	Wipe	RES	302	5/5	45 ± 24	0.045 ± 0.024
Glass	23	No	Wipe	RES	600	5/5	70 ± 10	0.070 ± 0.010
Glass	31	Yes	Ext. Eff.	RES	0	3/4	2 ± 3	0.002 ± 0.003
Glass	22	Yes	Scoping	RES	240	4/4	0 ± 0	0.000 ± 0.000
Glass	23	Yes	Wipe	RES	302	5/5	4 ± 4	0.004 ± 0.004
Glass	23	Yes	Wipe	RES	600	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	23	No	Wipe	RES	302	5/5	2 ± 1	0.002 ± 0.001
Polycarb.	23	No	Wipe	RES	600	5/5	196 ± 180	0.196 ± 0.180
Polycarb.	22	Yes	Scoping	RES	235	3/4	344 ± 17	0.344 ± 0.017
Polycarb.	23	Yes	Wipe	RES	302	5/5	120 ± 164	0.120 ± 0.164
Polycarb.	23	Yes	Wipe	RES	600	5/5	37 ± 21	0.037 ± 0.021
Silicone	24	No	Wipe	RES	300	5/5	1 ± 0	0.001 ± 0.000
Silicone	24	No	Wipe	RES	600	4/5	7 ± 13	0.007 ± 0.013
Silicone	31	Yes	Ext. Eff.	RES	0	4/4	280 ± 197	0.280 ± 0.197
Silicone	24	Yes	Wipe	RES	300	5/5	103 ± 24	0.103 ± 0.024
Silicone	22	Yes	Scoping	RES	479	4/4	13 ± 3	0.013 ± 0.003
Silicone	24	Yes	Wipe	RES	600	5/5	29 ± 5	0.029 ± 0.005

NOTE: Yellow = Combination of mVHP and pre-wipe technology, Gray = Exclusively pre-wipe technology, White = Exclusively mVHP technology

6.5 Contact Test Results Compared to ORDs for HD 10 g/m² Starting Challenge

The specified HD ORD values for JPID and JSSED are provided in Table 42. The post-decontamination contact test data for the approximately 10 g/m² HD starting challenge test was compared to the ORD contact hazard values and presented in Table 43 – Table 45.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The comparisons are only made to the JSSED ORD for this test as the JPID ORD specifies a 1 g/m² starting challenge. The data presented here corresponds to a 10 g/m² starting challenge.

Table 43 corresponds to the resulting contact hazard after wiping the coupons with the wipe technology (mVHP is not used). The results are summarized in the following list.

- **Aluminum** was decontaminated to meet the JSSED ORD using only the pre-wipe.
- **CARC** was decontaminated to meet the JSSED ORD using only the pre-wipe.
- **Glass** was decontaminated to meet the JSSED ORD using only the pre-wipe.
- **Silicone** was decontaminated to 1.56 times of the JSSED ORD using only the pre-wipe.

This data indicates that the pre-wipe method reduced the HD concentration detectible by the contact hazard test to less than 1 g/m² (1000 mg/m²) for aluminum, CARC, glass, and silicone. This was a good indication that the 1 g/m² starting challenge data may have been comparable to the JSSED ORD that specifies a 10 g/m² starting challenge, if the pre-wipe method is used. This effect has not yet been validated.

Table 44 corresponds to the resulting contact hazard after pre-wiping the coupons then applying mVHP. The results are summarized in the following list.

- **CARC** presents no contact hazard before 300 min of decontamination.
- **Glass** presents no contact hazard before 300 min of decontamination.
- **Polycarbonate** presents no contact hazard sometime 600 min of decontamination, and meets JSSED ORD before 300 min of decontamination.
- **Silicone** meets JSSED ORD before 300 min of decontamination.

Table 45 corresponds to the resulting contact hazard after using only the mVHP technology. The results are summarized in the following list.

- **CARC** had no contact hazard presented before 300 min of decontamination.
- **Glass** was decontaminated to the JSSED objective between 300 and 600 min of decontamination.
- **Polycarbonate** was decontaminated to the JSSED objective before 300 min of decontamination.
- **Silicone** was decontaminated to the JSSED objective between 300 and 600 min of decontamination.

Table 42. Contact ORD values for HD.

ORD	Starting Challenge (g/m²)	HD Contact Concentration (µg/m²)	(mg/m²)
JPID Threshold	1	3000	3.0
JPID Objective	1	0* (50)	0.0* (0.05)
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	100000	100

* This value was set as 0.0 mg/m² in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m² (when rounded to the presented accuracy would return a result of 0.1 mg/m²) fail the JPID objective level.

Table 43. Evaluation of pre-wipe method (exclusively) on HD 10 g/m² starting challenge.

Material	Wipe	Exp. Time (min)	Test Set	HD Contact Hazard (mg/m²)	JSSED Objective
Aluminum	Yes	0	15M	12.102 ± 3.400	0.12
			60M	1.870 ± 1.401	0.02
CARC	Yes	0	15M	57.271 ± 15.822	0.57
			60M	8.379 ± 5.607	0.08
Glass	Yes	0	15M	33.163 ± 15.887	0.33
			60M	5.323 ± 0.885	0.05
Silicone	Yes	0	15M	120.004 ± 8.130	1.20
			60M	155.779 ± 13.836	1.56

Table 44. Evaluation of contact test results for mVHP with pre-wipe on HD 10 g/m² starting challenge.

Material	Wipe	Exp.Time (min)	Test Set	HD Contact Hazard (mg/m²)	JSSED Objective
CARC	Yes	300	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
		600	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Glass	Yes	302	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
		600	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Polycarb.	Yes	302	15M	1.311 ± 0.692	0.01
			60M	3.372 ± 1.380	0.03
		600	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Silicone	Yes	300	15M	16.690 ± 3.073	0.17
			60M	21.976 ± 9.144	0.22
		600	15M	4.204 ± 1.805	0.04
			60M	6.505 ± 0.975	0.07

Table 45. Evaluation of mVHP (exclusively) on HD 10 g/m² starting challenge.

Material	Wipe	Exp.Time (min)	Test Set	HD Contact Hazard (mg/m²)	JSSED Objective
CARC	No	300	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
		600	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Glass	No	302	15M	3315.418 ± 1549.253	33.15
			60M	45.137 ± 41.563	0.45
		600	15M	1.209 ± 1.424	0.01
			60M	9.308 ± 6.777	0.09
Polycarb.	No	302	15M	57.212 ± 31.105	0.57
			60M	53.312 ± 38.897	0.53
		600	15M	1.445 ± 1.651	0.01
			60M	0.937 ± 0.212	0.01
Silicone	No	300	15M	135.876 ± 51.295	1.36
			60M	601.401 ± 130.428	6.01
		600	15M	50.896 ± 38.227	0.51
			60M	82.183 ± 62.919	0.82

7. TEST RESULTS AND DISCUSSION: TGD 1 g/m² TEST

7.1 Test Summary for TGD 1 g/m² Starting Challenge

The mVHP testing starting challenge was approximately 1 g/m² starting challenge applied as four 0.5 µL drops of TGD from a repeater syringe. The error bars presented in the tables and figures represent one standard deviation of the data. For each of the figures, the ORD values are drawn as solid lines. These values are reviewed in Table 5. Any data point above a solid line indicates that it did not meet the ORD value.

The conditions for each experimental run and exposure time are listed in Table 10 and Table 11. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

7.2 Vapor Test Results for TGD 1 g/m² Starting Challenge

The results of the vapor test for 1 g/m² starting challenge of TGD are presented in Table 46 – Table 49 and illustrated in Figure 37 – Figure 40. Four replicate coupons were measured for scoping runs, and five replicates were measured for efficacy runs, using each material with at least two exposure times each. These results are numerically compared to the ORDs in Section 7.3.

Table 46. TGD 1 g/m² starting challenge vapor results for glass and polycarbonate.

Material	Run	Run Type	Exp. Time (min)	Reps	TGD Vapor Concentration (μg/m³)	TGD Vapor Concentration (mg/m³)
Glass	9	Efficacy	120	5/5	1.02 ± 1.41	0.001024 ± 0.001406
Glass	9	Efficacy	298	5/5	0.05 ± 0.05	0.000048 ± 0.000049
Polycarb.	9	Efficacy	120	3/5	5.98 ± 2.49§	0.005979 ± 0.002486§
Polycarb.	7	Scoping	241	4/4	0.18 ± 0.11	0.000179 ± 0.000115
Polycarb.	9	Efficacy	298	5/5	0.12 ± 0.09	0.000121 ± 0.000093

§ - data represents a concentration greater than the calibration range, data is suspect.

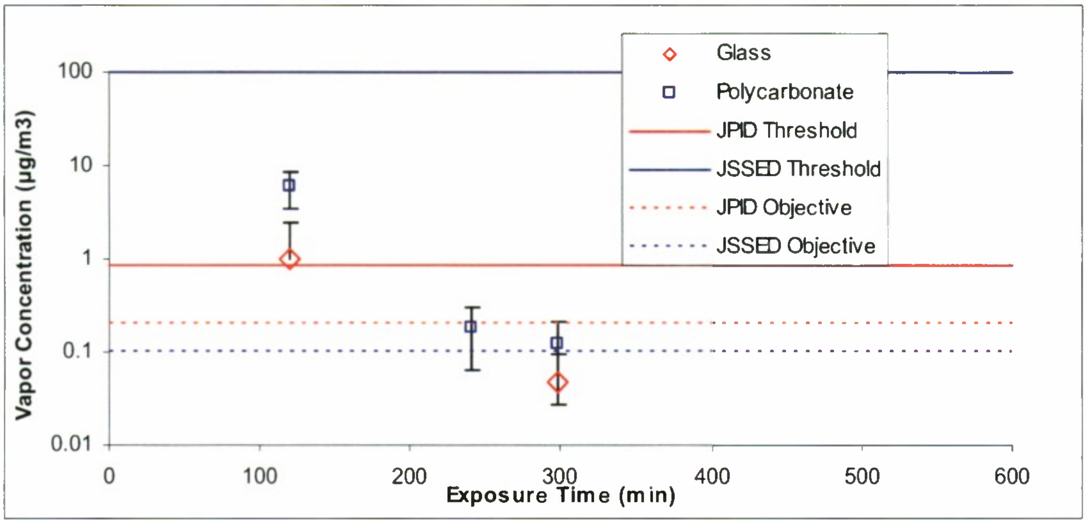


Figure 37. TGD vapor concentration vs. time for glass and polycarbonate.

Table 47. TGD 1 g/m² starting challenge vapor results for AF topcoat and CARC.

Material	Run	Run Type	Exp. Time (min)	Reps	TGD Vapor Concentration (μg/m³)	TGD Vapor Concentration (mg/m³)
AF topcoat	10	Efficacy	240	5/5	1.041 ± 0.503	0.001041 ± 0.000503
AF topcoat	10	Efficacy	480	4/5	0.181 ± 0.127	0.000181 ± 0.000127
CARC	10	Efficacy	240	4/5	0.10 ± 0.01	0.000097 ± 0.000014
CARC	7	Scoping	241	4/4	0.45 ± 0.34	0.000446 ± 0.000335
CARC	10	Efficacy	480	5/5	0.04 ± 0.04	0.000038 ± 0.000037

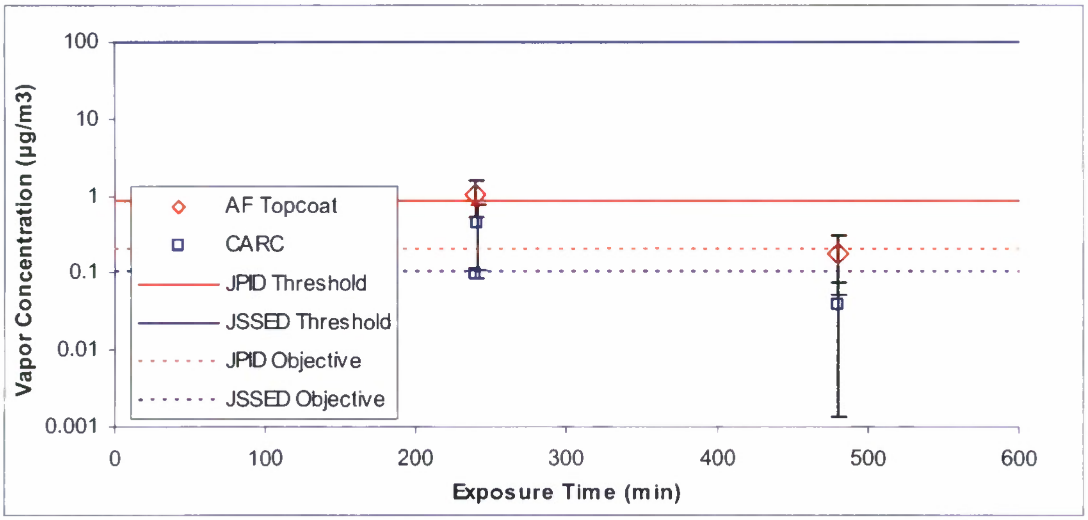


Figure 38. TGD vapor concentration vs. time for AF topcoat and CARC.

Table 48. TGD 1 g/m² starting challenge vapor results for silicone and Viton.

Material	Run	Run Type	Exp. Time (min)	Reps	TGD Vapor Concentration (µg/m³)	TGD Vapor Concentration (mg/m³)
Silicone	7	Scoping	241	2/2	7.80 ± 0.32	0.007797 ± 0.000321
Silicone	10	Efficacy	480	5/5	11.63 ± 2.63§	0.011632 ± 0.002628§
Silicone	10	Wipe/Eff	600	5/5	0.920 ± 1.140	0.000920 ± 0.001140
Viton	10	Efficacy	480	5/5	9.49 ± 1.25§	0.009491 ± 0.001249§
Viton	13	Wipe	600	5/5	2.83 ± 0.25§	0.002834 ± 0.000253§

§ - data represents a concentration greater than the calibration range, data is suspect.

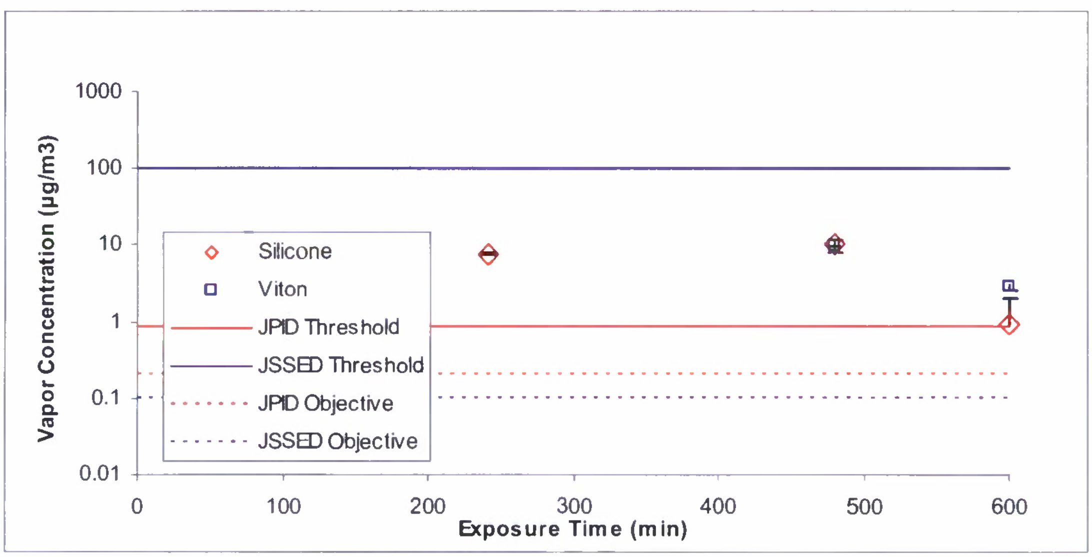


Figure 39. TGD vapor concentration vs. time for silicone and Viton.

Table 49. TGD 1 g/m² starting challenge vapor results for aluminum and Kapton.

Material	Run	Run Type	Exp. Time (min)	Reps	TGD Vapor Concentration (μg/m³)	TGD Vapor Concentration (mg/m³)
Aluminum	9	Efficacy	120	1/5	6.97 ± 0.00	0.006974 ± 0.000000
Aluminum	7	Scoping	241	4/4	0.18 ± 0.19	0.000184 ± 0.000194
Aluminum	9	Efficacy	298	4/5	0.01 ± 0.00	0.000015 ± 0.000004
Kapton	9	Efficacy	120	1/5	6.025 ± 0.000§	0.006025 ± 0.000000§
Kapton	9	Efficacy	298	5/5	0.06 ± 0.06	0.000058 ± 0.000059

§ - data represents a concentration greater than the calibration range, data is suspect.

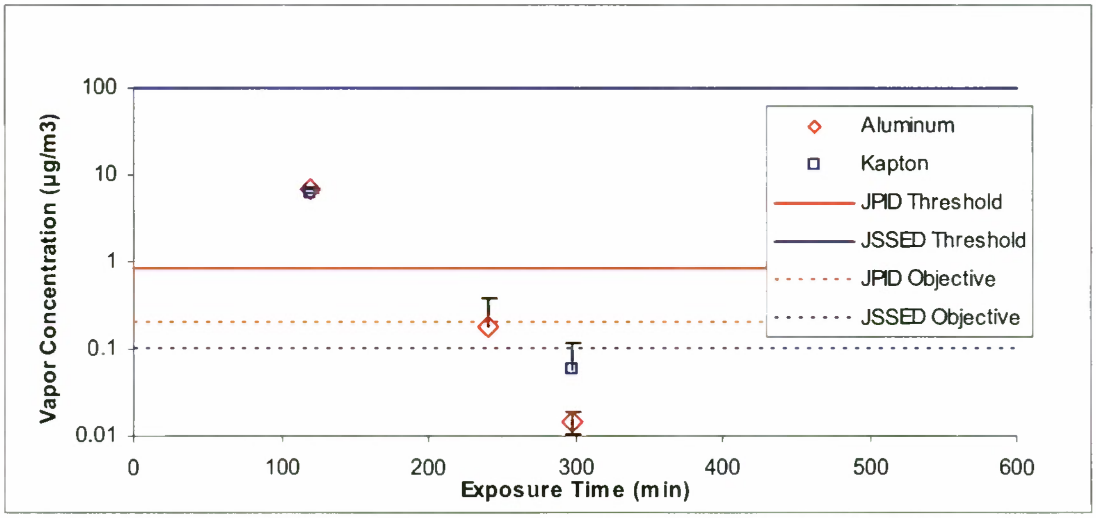


Figure 40. TGD vapor concentration vs. time for aluminum and Kapton.

7.3 Vapor Test Results Compared to ORDs for TGD 1 g/m² Starting Challenge

The specified TGD ORD values for JPID and JSSED are provided in Table 50. The post-decontamination vapor test data for the approximately 1 g/m² starting challenge of TGD is directly compared to the ORD vapor hazard values and presented in Table 51.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The Table 51 results for a 1 g/m² starting challenge of TGD are summarized in the following list.

- **AF Topcoat** met the JPID objective ORD after 480 min of decontamination.
- **Aluminum** met JPID objective ORD after 298 min of decontamination.
- **CARC** met the JPID objective ORD after 240 min of decontamination.
- **Glass** met the JPID objective ORD after 298 min of decontamination.
- **Kapton** met the JPID objective ORD after 298 min of decontamination.
- **Polycarbonate** met JPID objective ORD after 298 min of decontamination.
- **Silicone** presented a vapor hazard 4.6 times JPID objective ORD, but passed both JPID and JSSED threshold ORDs after 600 min of decontamination.

- **Viton** presented a vapor hazard 14.17 times JPID objective ORD, but passed the JSSED threshold ORD after 600 min of decontamination.

The JSSED ORD values specify a 10 g/m^2 starting challenge. The data presented here corresponds to a 1 g/m^2 starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m^2 to 1 g/m^2 for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m^2 data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m^2 data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 50. Vapor ORD values for TGD.

ORD	Starting Challenge (g/m^2)	TGD Vapor Concentration	
		(µg/m^3)	(mg/m^3)
JPID Threshold	1	0.87	0.00087
JPID Objective	1	0.2	0.0002
JSSED Threshold	10	100	0.1
JSSED Objective	10	0.1	0.0001

Table 51. Vapor efficacy of mVHP on TGD: 1 g/m^2 starting challenge.

Material	Exp. Time (min)	TGD Vapor Concentration (mg/m^3)	JPID Thresh. Factor	JSSED Thresh. Factor	JPID Obj. Factor	JSSED Obj. Factor
AF Topcoat	240	0.001041 ± 0.000503	1.20	0.01	5.21	10.41
	480	0.000181 ± 0.000127	0.21	0.00	0.90	1.81
Aluminum	120	0.006974 ± 0.000000	8.02	0.07	34.87	69.74
	298	0.000015 ± 0.000004	0.02	0.00	0.07	0.15
CARC	240	0.000097 ± 0.000014	0.11	0.00	0.49	0.97
	480	0.000038 ± 0.000037	0.04	0.00	0.19	0.38
Glass	120	0.001024 ± 0.001406	1.18	0.01	5.12	10.24
	298	0.000048 ± 0.000049	0.05	0.00	0.24	0.48
Kapton	120	0.006025 ± 0.000000§	6.93§	0.06§	30.13§	60.25§
	298	0.000058 ± 0.000059	0.07	0.00	0.29	0.58
Polycarb.	120	0.005979 ± 0.002486§	6.87§	0.06§	29.90§	59.79§
	298	0.000121 ± 0.000093	0.14	0.00	0.60	1.21
Silicone	480	0.011632 ± 0.002628	12.06	0.10	52.48	104.96
	600	0.000920 ± 0.001140	1.06	0.01	4.60	9.20
Viton	480	0.009491 ± 0.001249	10.30	0.09	44.79	89.58
	600	0.002834 ± 0.000253	3.26	0.03	14.17	28.34

§ - data represents a concentration greater than the calibration range, data is suspect.

7.4 Contact Test Results for TGD 1 g/m² Starting Challenge

The results of the contact test for TGD 1 g/m² starting challenge are presented in Table 52 to Table 59, and illustrated in Figure 41 to Figure 48 using semi-log plots. The contact test analysis methods are discussed in Section 2.10.1.

There were four types of runs used in the contact hazard analysis: baseline, extraction efficiency (ext. eff.), scoping, and efficacy. The baseline and extraction efficiency runs used no decontaminant. The baseline and extraction efficiency runs are highlighted in gray in Table 52 to Table 59 because they do not represent decontamination efficacy data (i.e., CT hydrogen peroxide = 0.0). They provide a baseline for the response for natural agent weathering at ambient conditions (i.e., no mVHP treatment). For each of the graphs, the "baseline" data includes both the baseline run and the extraction efficiency run (used for exposure time zero). In a similar fashion, the "efficacy" data presented in the graphs includes both efficacy and scoping data (if available).

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric, this occurs because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, thus producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table reports a value of zero, a value of 1 μg/m² has been assigned so that the data point can be plotted on the graph. There was no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 5.5.

The difference in results for baseline data between runs 8 and 28 is a result of the temperature for the runs, 21.6 ± 0.4°C and 13.7 ± 0.8 °C, respectively.

In addition to the 15M and 60M test specified in the TOP, a residual extraction analysis was performed on each contact sample (Table 60). The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, these values under estimated the actual residual agent that was present. The acquisition of these results was not specified in the TOP or the ORDs and, therefore, the results have no comparison to ORD values.

Table 52. TGD 1 g/m² starting challenge contact test results for AF topcoat.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (μg/m²)	TGD Contact Concentration (mg/m²)
AF topcoat	32	Ext. Eff.	15M	0	3/4	192690 ± 8681	192.690 ± 8.681
AF topcoat	8	Baseline	15M	60	3/3	2306 ± 451	2.306 ± 0.451
AF topcoat	28	Baseline	15M	63	3/3	86969 ± 32389	86.969 ± 32.389
AF topcoat	8	Baseline	15M	241	3/3	965 ± 327	0.965 ± 0.327
AF topcoat	10	Efficacy	15M	240	3/5	0 ± 0	0.000 ± 0.000
AF topcoat	10	Efficacy	15M	480	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	32	Ext. Eff.	60M	0	4/4	86214 ± 14334	86.214 ± 14.334
AF topcoat	8	Baseline	60M	60	3/3	5661 ± 1764	5.661 ± 1.764
AF topcoat	28	Baseline	60M	63	3/3	31685 ± 12485	31.685 ± 12.485
AF topcoat	8	Baseline	60M	241	3/3	2716 ± 235	2.716 ± 0.235
AF topcoat	10	Efficacy	60M	240	5/5	0 ± 0	0.000 ± 0.000
AF topcoat	10	Efficacy	60M	480	5/5	0 ± 0	0.000 ± 0.000

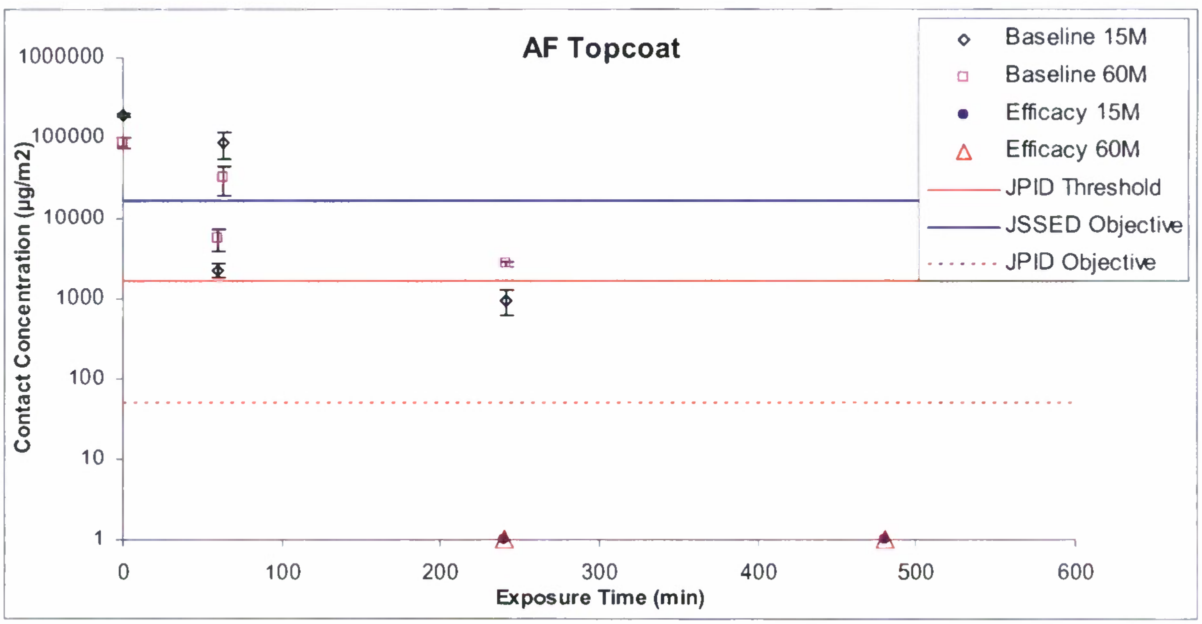


Figure 41. TGD contact concentration vs. time for AF topcoat.

Table 53. TGD 1 g/m² starting challenge contact test results for aluminum.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (μg/m²)	TGD Contact Concentration (mg/m²)
Aluminum	32	Ext. Eff.	15M	0	4/4	252302 ± 132825	252.302 ± 132.825
Aluminum	8	Baseline	15M	60	3/3	366 ± 38	0.366 ± 0.038
Aluminum	28	Baseline	15M	63	3/3	242726 ± 105114	242.726 ± 105.114
Aluminum	8	Baseline	15M	241	3/3	222 ± 216	0.222 ± 0.216
Aluminum	9	Efficacy	15M	120	5/5	1988 ± 1448	1.988 ± 1.448
Aluminum	7	Scoping	15M	241	4/4	0 ± 0	0.000 ± 0.000
Aluminum	9	Efficacy	15M	298	4/5	138 ± 2	0.138 ± 0.002
Aluminum	32	Ext. Eff.	60M	0	4/4	102343 ± 16745	102.343 ± 16.745
Aluminum	8	Baseline	60M	60	3/3	430 ± 77	0.430 ± 0.077
Aluminum	28	Baseline	60M	63	3/3	58113 ± 23805	58.113 ± 23.805
Aluminum	8	Baseline	60M	241	3/3	333 ± 214	0.333 ± 0.214
Aluminum	9	Efficacy	60M	120	5/5	1093 ± 760	1.093 ± 0.760
Aluminum	7	Scoping	60M	241	4/4	0 ± 0	0.000 ± 0.000
Aluminum	9	Efficacy	60M	298	5/5	79 ± 72	0.079 ± 0.072

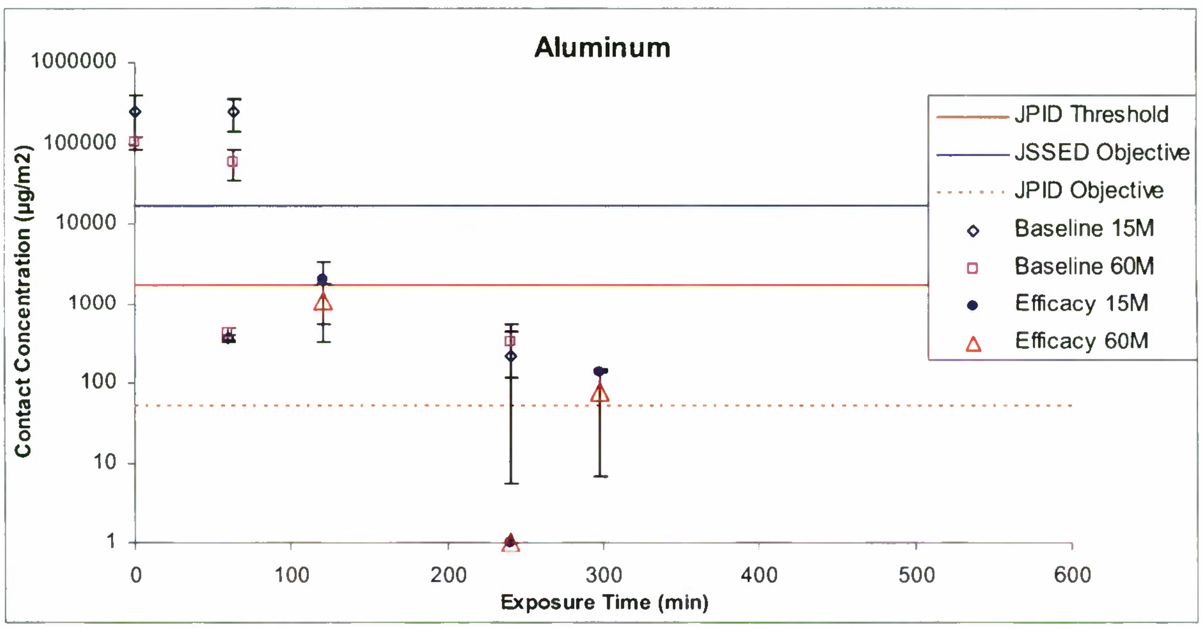


Figure 42. TGD contact concentration vs. time for aluminum.

Table 54. TGD 1 g/m² starting challenge contact test results for CARC.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (μg/m²)	TGD Contact Concentration (mg/m²)
CARC	32	Ext. Eff.	15M	0	4/4	88056 ± 68689	88.056 ± 68.689
CARC	8	Baseline	15M	60	3/3	473 ± 65	0.473 ± 0.065
CARC	28	Baseline	15M	63	3/3	99989 ± 102896	99.989 ± 102.896
CARC	8	Baseline	15M	241	3/3	544 ± 414	0.544 ± 0.414
CARC	7	Scoping	15M	241	4/4	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	15M	240	2/5	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	15M	480	5/5	0 ± 0	0.000 ± 0.000
CARC	32	Ext. Eff.	60M	0	4/4	14296 ± 12046	14.296 ± 12.046
CARC	8	Baseline	60M	60	2/3	558 ± 2	0.558 ± 0.002
CARC	28	Baseline	60M	63	3/3	14648 ± 9781	14.648 ± 9.781
CARC	8	Baseline	60M	241	2/3	811 ± 5	0.811 ± 0.005
CARC	7	Scoping	60M	241	4/4	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	60M	240	5/5	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	60M	480	5/5	0 ± 0	0.000 ± 0.000

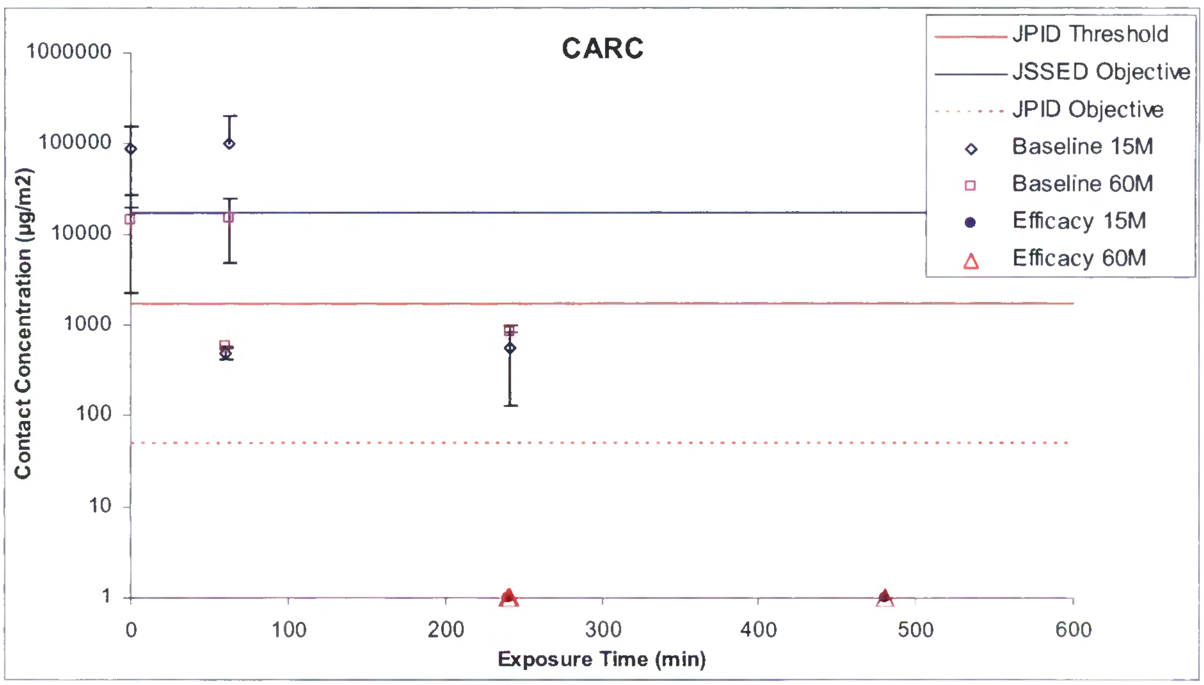


Figure 43. TGD contact concentration vs. time for CARC.

Table 55. TGD 1 g/m² starting challenge hazard contact results for glass.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (μg/m²)	TGD Contact Concentration (mg/m²)
Glass	32	Ext. Eff.	15M	0	4/4	426153 ± 61546	426.153 ± 61.546
Glass	8	Baseline	15M	60	3/3	360 ± 82	0.360 ± 0.082
Glass	28	Baseline	15M	63	3/3	104365 ± 44129	104.365 ± 44.129
Glass	8	Baseline	15M	241	3/3	426 ± 92	0.426 ± 0.092
Glass	9	Efficacy	15M	120	4/5	8772 ± 8142	8.772 ± 8.142
Glass	9	Efficacy	15M	298	5/5	148 ± 15	0.148 ± 0.015
Glass	32	Ext. Eff.	60M	0	3/4	1232 ± 839	1.232 ± 0.839
Glass	8	Baseline	60M	60	3/3	401 ± 177	0.401 ± 0.177
Glass	28	Baseline	60M	63	3/3	15127 ± 10642	15.127 ± 10.642
Glass	8	Baseline	60M	241	3/3	416 ± 148	0.416 ± 0.148
Glass	9	Efficacy	60M	120	5/5	4166 ± 2726	4.166 ± 2.726
Glass	9	Efficacy	60M	298	5/5	106 ± 64	0.106 ± 0.064

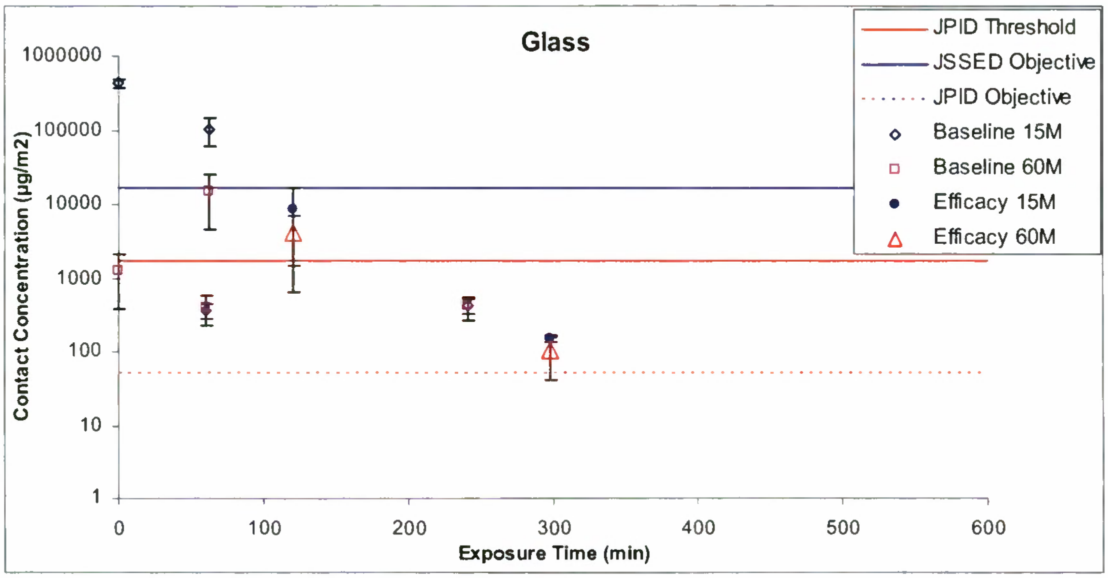


Figure 44. TGD contact concentration vs. time for glass.

Table 56. TGD 1 g/m² starting challenge contact test results for Kapton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (μg/m²)	TGD Contact Concentration (mg/m²)
Kapton	32	Ext. Eff.	15M	0	4/4	174787 ± 44221	174.787 ± 44.221
Kapton	8	Baseline	15M	60	3/3	244 ± 34	0.244 ± 0.034
Kapton	28	Baseline	15M	63	3/3	72608 ± 7786	72.608 ± 7.786
Kapton	8	Baseline	15M	241	3/3	496 ± 41	0.496 ± 0.041
Kapton	9	Efficacy	15M	120	5/5	8398 ± 4241	8.398 ± 4.241
Kapton	9	Efficacy	15M	298	5/5	138 ± 11	0.138 ± 0.011
Kapton	32	Ext. Eff.	60M	0	4/4	124477 ± 60103	124.477 ± 60.103
Kapton	8	Baseline	60M	60	3/3	312 ± 130	0.312 ± 0.130
Kapton	28	Baseline	60M	63	3/3	15441 ± 16677	15.441 ± 16.677
Kapton	8	Baseline	60M	241	3/3	529 ± 216	0.529 ± 0.216
Kapton	9	Efficacy	60M	120	5/5	5471 ± 1942	5.471 ± 1.942
Kapton	9	Efficacy	60M	298	4/5	144 ± 6	0.144 ± 0.006

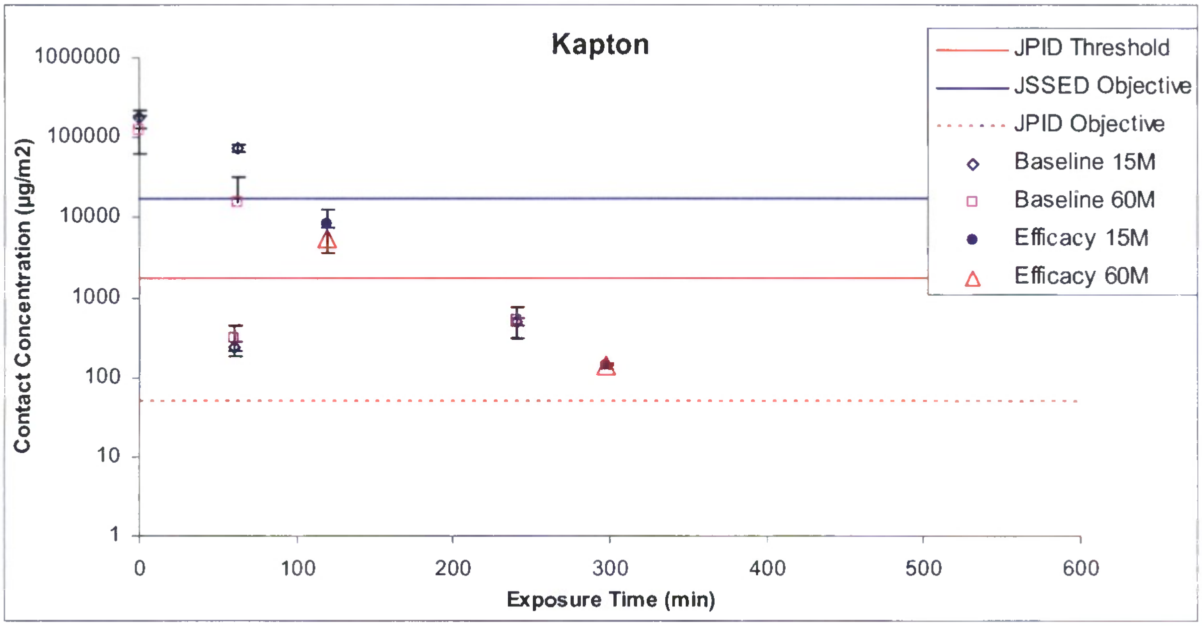


Figure 45. TGD contact concentration vs. time for Kapton.

Table 57. TGD 1 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (µg/m²)	TGD Contact Concentration (mg/m²)
Polycarb.	32	Ext. Eff.	15M	0	4/4	310074 ± 116657	310.074 ± 116.657
Polycarb.	8	Baseline	15M	60	3/3	142 ± 23	0.142 ± 0.023
Polycarb.	28	Baseline	15M	63	2/3	108346 ± 36947	108.346 ± 36.947
Polycarb.	8	Baseline	15M	241	3/3	446 ± 36	0.446 ± 0.036
Polycarb.	9	Efficacy	15M	120	5/5	5294 ± 3514	5.294 ± 3.514
Polycarb.	7	Scoping	15M	241	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	9	Efficacy	15M	298	5/5	146 ± 11	0.146 ± 0.011
Polycarb.	32	Ext. Eff.	60M	0	4/4	46466 ± 36289	46.466 ± 36.289
Polycarb.	8	Baseline	60M	60	3/3	365 ± 109	0.365 ± 0.109
Polycarb.	28	Baseline	60M	63	2/3	52110 ± 12338	52.110 ± 12.338
Polycarb.	8	Baseline	60M	241	3/3	480 ± 95	0.480 ± 0.095
Polycarb.	9	Efficacy	60M	120	5/5	2283 ± 1515	2.283 ± 1.515
Polycarb.	7	Scoping	60M	241	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	9	Efficacy	60M	298	4/5	146 ± 9	0.146 ± 0.009

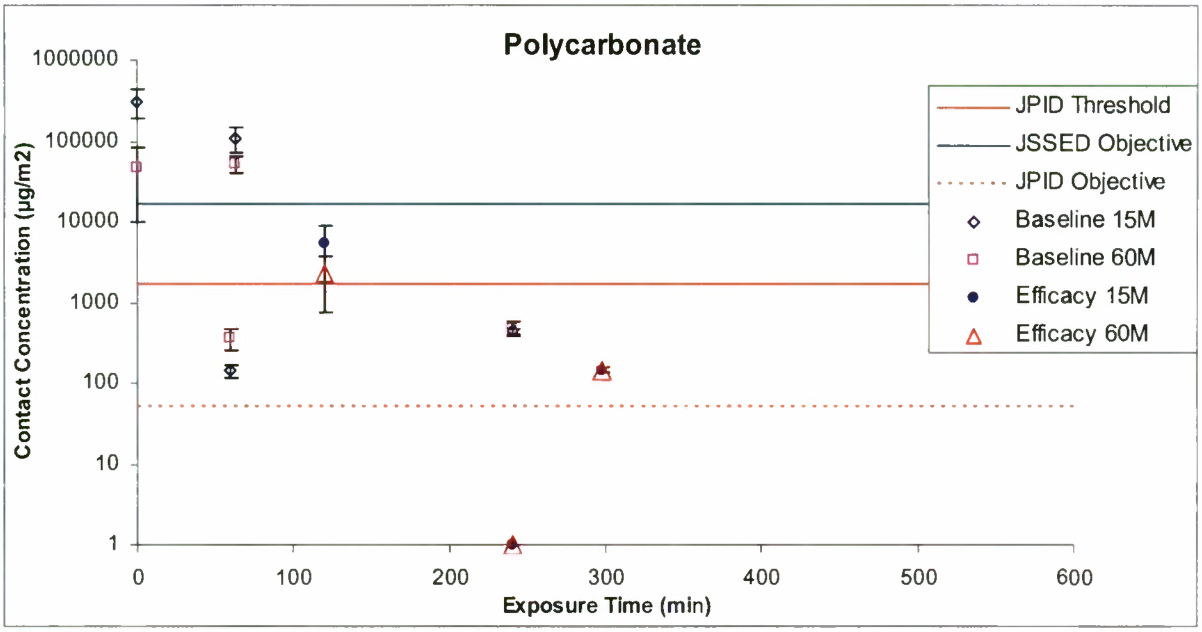


Figure 46. TGD contact concentration vs. time for polycarbonate.

Table 58. TGD 1 g/m² starting challenge contact test results for silicone.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (µg/m²)	TGD Contact Concentration (mg/m²)
Silicone	32	Ext. Eff.	15M	0	3/4	9408 ± 1977	9.408 ± 1.977
Silicone	8	Baseline	15M	241	3/3	5027 ± 2022	5.027 ± 2.022
Silicone	8	Baseline	15M	480	3/3	1991 ± 258	1.991 ± 0.258
Silicone	7	Scoping	15M	241	4/4	1701 ± 271	1.701 ± 0.271
Silicone	10	Efficacy	15M	240	5/5	2610 ± 299	2.610 ± 0.299
Silicone	10	Efficacy	15M	480	5/5	1046 ± 293	1.046 ± 0.293
Silicone	13	Wipe*	15M	600	5/5	1094 ± 381	1.094 ± 0.381
Silicone	32	Ext. Eff.	60M	0	4/4	21678 ± 2634	21.678 ± 2.634
Silicone	8	Baseline	60M	241	3/3	14260 ± 4081	14.260 ± 4.081
Silicone	8	Baseline	60M	480	2/3	7648 ± 44	7.648 ± 0.044
Silicone	7	Scoping	60M	241	4/4	5084 ± 499	5.084 ± 0.499
Silicone	10	Efficacy	60M	240	5/5	5442 ± 948	5.442 ± 0.948
Silicone	10	Efficacy	60M	480	5/5	3483 ± 367	3.483 ± 0.367
Silicone	13	Wipe*	60M	600	5/5	1861 ± 786	1.861 ± 0.786

* The data from run 13 is indicated as a wipe type run; these samples were not pre-wiped and were contaminated with 1 g/m² starting challenge. These samples were included in a wipe run to provide a data point at 600 min of exposure.

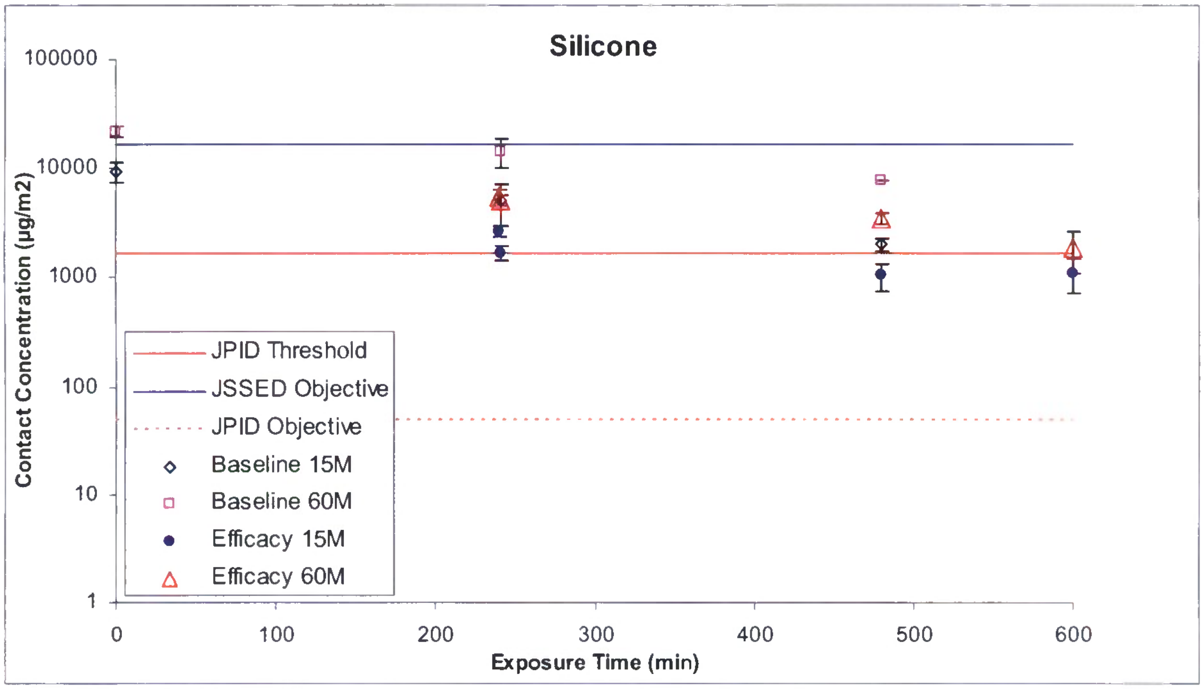


Figure 47. TGD contact concentration vs. time for silicone.

Table 59. TGD 1 g/m² starting challenge contact test results for Viton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (µg/m²)	TGD Contact Concentration (mg/m²)
Viton	32	Ext. Eff.	15M	0	4/4	25757 ± 10426	25.757 ± 10.426
Viton	8	Baseline	15M	241	3/3	7697 ± 4552	7.697 ± 4.552
Viton	8	Baseline	15M	480	2/3	1924 ± 3	1.924 ± 0.003
Viton	10	Efficacy	15M	240	5/5	1086 ± 451	1.086 ± 0.451
Viton	10	Efficacy	15M	480	5/5	185 ± 259	0.185 ± 0.259
Viton	13	Wipe*	15M	600	5/5	303 ± 129	0.303 ± 0.129
Viton	32	Ext. Eff.	60M	0	3/4	69261 ± 5703	69.261 ± 5.703
Viton	8	Baseline	60M	241	3/3	18414 ± 9310	18.414 ± 9.310
Viton	8	Baseline	60M	480	3/3	6460 ± 208	6.460 ± 0.208
Viton	10	Efficacy	60M	240	5/5	3299 ± 847	3.299 ± 0.847
Viton	10	Efficacy	60M	480	5/5	1575 ± 385	1.575 ± 0.385
Viton	13	Wipe*	60M	600	5/5	453 ± 141	0.453 ± 0.141

* The data from run 13 is indicated as a wipe type run; these samples were not pre-wiped and were contaminated with 1 g/m² starting challenge. These samples were included in another run to provide a data point at 600 min of exposure.

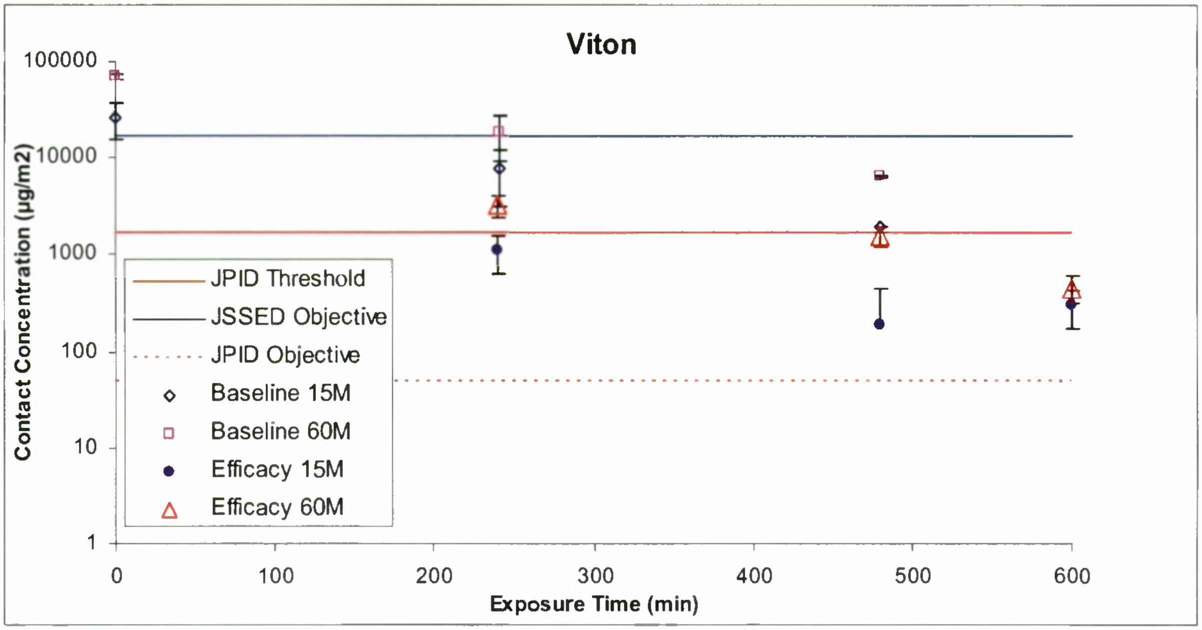


Figure 48. TGD contact concentration vs. time for Viton.

Table 60. TGD 1 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (µg/m²)	TGD Contact Concentration (mg/m²)
AF topcoat	32	Ext. Eff.	RES	0	4/4	85160 ± 14348	85.160 ± 14.348
AF topcoat	8	Baseline	RES	60	3/3	87 ± 42	0.087 ± 0.042
AF topcoat	28	Baseline	RES	63	3/3	83276 ± 15985	83.276 ± 15.985
AF topcoat	8	Baseline	RES	241	3/3	85 ± 5	0.085 ± 0.005
AF topcoat	10	Efficacy	RES	240	5/5	9 ± 7	0.009 ± 0.007
AF topcoat	10	Efficacy	RES	480	5/5	8 ± 1	0.008 ± 0.001
Aluminum	32	Ext. Eff.	RES	0	4/4	9225 ± 5369	9.225 ± 5.369
Aluminum	8	Baseline	RES	60	2/3	8 ± 0	0.008 ± 0.000
Aluminum	28	Baseline	RES	63	3/3	4558 ± 4258	4.558 ± 4.258
Aluminum	8	Baseline	RES	241	3/3	7 ± 2	0.007 ± 0.002
Aluminum	9	Efficacy	RES	120	5/5	106 ± 158	0.106 ± 0.158
Aluminum	7	Scoping	RES	241	4/4	0 ± 0	0.000 ± 0.000
Aluminum	9	Efficacy	RES	298	5/5	0 ± 0	0.000 ± 0.000
CARC	32	Ext. Eff.	RES	0	3/4	1521 ± 318	1.521 ± 0.318
CARC	8	Baseline	RES	60	3/3	7 ± 1	0.007 ± 0.001
CARC	28	Baseline	RES	63	3/3	2264 ± 881	2.264 ± 0.881
CARC	8	Baseline	RES	241	3/3	13 ± 3	0.013 ± 0.003
CARC	7	Scoping	RES	241	4/4	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	RES	240	5/5	0 ± 0	0.000 ± 0.000
CARC	10	Efficacy	RES	480	5/5	0 ± 0	0.000 ± 0.000
Glass	32	Ext. Eff.	RES	0	3/4	154 ± 20	0.154 ± 0.020
Glass	8	Baseline	RES	60	3/3	6 ± 3	0.006 ± 0.003
Glass	28	Baseline	RES	63	3/3	3316 ± 2027	3.316 ± 2.027
Glass	8	Baseline	RES	241	3/3	6 ± 3	0.006 ± 0.003
Glass	9	Efficacy	RES	120	5/5	4 ± 2	0.004 ± 0.002
Glass	9	Efficacy	RES	298	5/5	0 ± 0	0.000 ± 0.000

Table 60. TGD 1 g/m² starting challenge contact test residual agent results for all materials (continued).

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Concentration (µg/m²)	TGD Contact Concentration (mg/m²)
Kapton	32	Ext. Eff.	RES	0	4/4	2441 ± 1681	2.441 ± 1.681
Kapton	8	Baseline	RES	60	3/3	5 ± 2	0.005 ± 0.002
Kapton	28	Baseline	RES	63	3/3	647 ± 657	0.647 ± 0.657
Kapton	8	Baseline	RES	241	2/3	8 ± 0	0.008 ± 0.000
Kapton	9	Efficacy	RES	120	5/5	2 ± 1	0.002 ± 0.001
Kapton	9	Efficacy	RES	298	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	32	Ext. Eff.	RES	0	4/4	1920 ± 1825	1.920 ± 1.825
Polycarb.	8	Baseline	RES	60	3/3	6 ± 1	0.006 ± 0.001
Polycarb.	28	Baseline	RES	63	2/3	5963 ± 446	5.963 ± 0.446
Polycarb.	8	Baseline	RES	241	3/3	6 ± 2	0.006 ± 0.002
Polycarb.	9	Efficacy	RES	120	5/5	148 ± 215	0.148 ± 0.215
Polycarb.	7	Scoping	RES	241	4/4	108 ± 93	0.108 ± 0.093
Polycarb.	9	Efficacy	RES	298	5/5	0 ± 0	0.000 ± 0.000
Silicone	32	Ext. Eff.	RES	0	3/4	455813 ± 30669	455.813 ± 30.669
Silicone	8	Baseline	RES	241	2/3	0 ± 0	0.000 ± 0.000
Silicone	8	Baseline	RES	480	2/3	376 ± 4	0.376 ± 0.004
Silicone	7	Scoping	RES	241	3/4	260521 ± 4197	260.521 ± 4.197
Silicone	10	Efficacy	RES	240	5/5	267 ± 107	0.267 ± 0.107
Silicone	10	Efficacy	RES	480	5/5	204 ± 38	0.204 ± 0.038
Silicone	13	Wipe	RES	600	4/5	92 ± 13	0.092 ± 0.013
Viton	32	Ext. Eff.	RES	0	4/4	339940 ± 163350	339.940 ± 163.350
Viton	8	Baseline	RES	241	2/3	0 ± 0	0.000 ± 0.000
Viton	8	Baseline	RES	480	2/3	0 ± 0	0.000 ± 0.000
Viton	10	Efficacy	RES	240	5/5	179 ± 141	0.179 ± 0.141
Viton	10	Efficacy	RES	480	5/5	226 ± 62	0.226 ± 0.062
Viton	13	Wipe	RES	600	5/5	112 ± 92	0.112 ± 0.092

7.5 Contact Test Results Compared to ORD for TGD 1 g/m² Starting Challenge

The specified TGD ORD values for JPID and JSSED are provided in Table 61. The post-decontamination vapor test data for the approximately 1 g/m² TGD starting challenge test was directly compared to the ORD contact hazard values and is presented in Table 62.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The results are summarized in the following list.

- **AF Topcoat** met the JPID objective ORD before 240 min of decontamination.
- **Aluminum** was a factor of 2.77 times the JPID objective ORD after 298 min of decontamination, but met the JPID threshold and JSSED objective ORDs.
- **CARC** met the JPID objective ORD before 240 min of decontamination.
- **Glass** was a factor of 3.0 times the JPID objective ORD after 298 min of decontamination, but met the JPID threshold and JSSED objective ORDs.
- **Kapton** was a factor of 2.8 times the JPID objective ORD after 298 min of decontamination, but met the JPID threshold and JSSED objective ORDs.

- **Polycarbonate** was a factor of 2.9 times the JPID objective ORD after 298 min of decontamination, but met the JPID threshold and JSSED objective ORDs.
- **Silicone** was a factor of 22 times the JPID objective ORD after 600 min of decontamination, but met the JSSED objective ORDs. The 60M test shows a higher hazard than the 15M tests.
- **Viton** met the JPID objective ORD before 480 min of decontamination.

The JSSED ORD values specify a 10 g/m^2 starting challenge. The data presented here corresponds to a 1 g/m^2 starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m^2 to 1 g/m^2 for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m^2 data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m^2 data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 61. Contact ORD values for TGD.

ORD	Starting Challenge (g/m^2)	TGD Contact Concentration	
		($\mu g/m^2$)	(mg/m^2)
JPID Threshold	1	1700	1.7
JPID Objective	1	0* (0.5)	0.0* (0.05)
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	16700	16.7

* This value was set as 0.0 mg/m^2 in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m^2 (when rounded to the presented accuracy would return a result of 0.1 mg/m^2) fail the JPID objective level.

Table 62. TGD 1 g/m² starting challenge contact test results compared to ORD.

Material	Exp. Time (min)	Test Set	TGD Contact Concentration (mg/m²)	JPID Threshold Factor	JSSED Objective. Factor	JPID Objective. Factor
AF topcoat	240	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	480	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Aluminum	120	15M	1.988 ± 1.448	1.17	0.12	39.76
		60M	1.093 ± 0.760	0.64	0.07	21.86
	241	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	298	15M	0.138 ± 0.002	0.08	0.01	2.77
		60M	0.079 ± 0.072	0.05	0.00	1.57
CARC	240	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	241	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	480	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Glass	120	15M	8.772 ± 8.142	5.16	0.53	175.45
		60M	4.166 ± 2.726	2.45	0.25	83.32
	298	15M	0.148 ± 0.015	0.09	0.01	2.97
		60M	0.106 ± 0.064	0.06	0.01	2.12
Kapton	120	15M	8.398 ± 4.241	4.94	0.50	167.97
		60M	5.471 ± 1.942	3.22	0.33	109.42
	298	15M	0.138 ± 0.011	0.08	0.01	2.77
		60M	0.144 ± 0.006	0.08	0.01	2.88
Polycarb.	120	15M	5.294 ± 3.514	3.11	0.32	105.88
		60M	2.283 ± 1.515	1.34	0.14	45.67
	241	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	298	15M	0.146 ± 0.011	0.09	0.01	2.92
		60M	0.146 ± 0.009	0.09	0.01	2.93
Silicone	240	15M	1.701 ± 0.271	1.00	0.10	34.02
		60M	5.084 ± 0.499	2.99	0.30	101.69
	241	15M	2.610 ± 0.299	1.54	0.16	52.20
		60M	5.442 ± 0.948	3.20	0.33	108.85
	480	15M	1.046 ± 0.293	0.62	0.06	20.91
		60M	3.483 ± 0.367	2.05	0.21	69.65
	600	15M	1.086 ± 0.451	0.64	0.07	21.72
		60M	3.299 ± 0.847	1.94	0.20	65.98
Viton	240	15M	0.185 ± 0.259	0.11	0.01	3.70
		60M	1.575 ± 0.385	0.93	0.09	31.50
	480	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	600	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00

8. TEST RESULTS AND DISCUSSION: TGD 10 g/m^2 TEST

8.1 Test Summary for TGD 10 g/m^2 Starting Challenge

The 10 g/m^2 starting challenge loading was used to evaluate both mVHP and pre-wipe technologies. For specified samples the coupon was wiped before the mVHP decontamination. The 10 g/m^2 starting challenge was applied as four 5.0 µL drops from a repeater pipette. The error bars presented represent one standard deviation of the data. For each of the figures the ORD values are drawn as solid lines. Any data point above a solid line indicates that it did not meet the ORD value.

The conditions for each experimental run and exposure time are listed in the figures. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

8.2 Vapor Test Results for TGD 10 g/m^2 Starting Challenge

The results of the vapor test for 10 g/m^2 starting challenge of TGD are presented in Table 63 – Table 64 and illustrated in Figure 49 – Figure 50. These results are numerically compared to the ORD in Section 8.3.

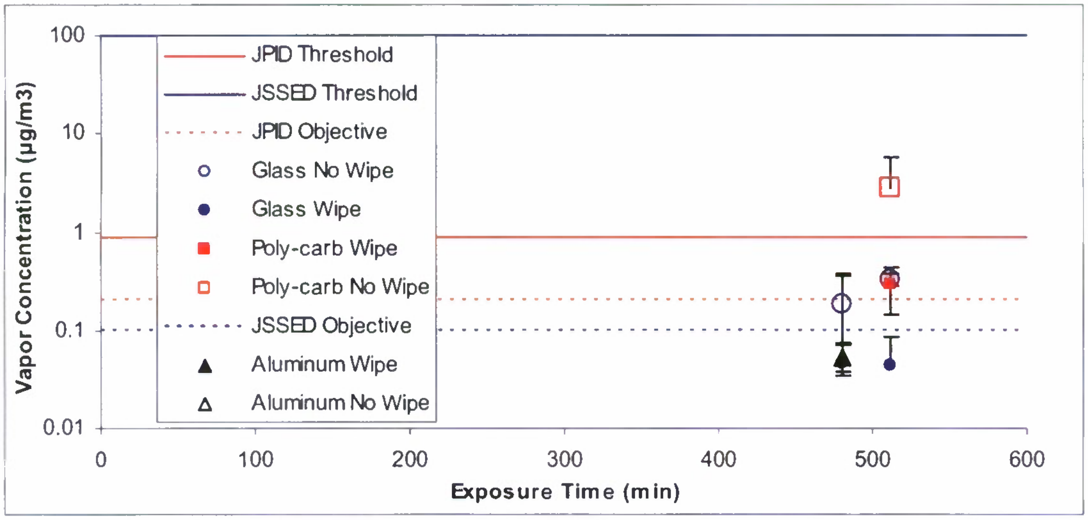
In the following tables, samples that were pre-wiped will be indicated by a "Yes" value in the wiped column. Results that represent the combination of the pre-wipe method and mVHP will be highlighted in gray. Results for samples that are not pre-wiped (mVHP technology only) are not highlighted.

Table 63. TGD 10 g/m^2 starting challenge vapor test data for glass and polycarbonate.

Material	Run	Run Type	Wiped	Exp. Time (min)	Reps	TGD Vapor Concentration (µg/m^3)	TGD Vapor Concentration (mg/m^3)
Aluminum	11	Scoping	No	480	3/3	0.05 ± 0.02	0.000054 ± 0.000019
	11	Scoping	**Yes**	**480**	**3/3**	**0.04 ± 0.02**	**0.000035 ± 0.000016**
Glass	11	Scoping	No	480	2/3	0.18 ± 0.02	0.000183 ± 0.000018
	12	Wipe	No	512	3/5	0.33 ± 0.34	0.000325 ± 0.000342
	11	Scoping	**Yes**	**480**	**2/2**	**0.05 ± 0.03**	**0.000046 ± 0.000027**
	12	Wipe	**Yes**	**512**	**5/5**	**0.04 ± 0.02**	**0.000044 ± 0.000019**
Polycarb.	12	Wipe	No	512	5/5	2.74 ± 2.94§	0.002737 ± 0.002943§
	12	Wipe	**Yes**	**512**	**5/5**	**0.29 ± 0.15**	**0.000291 ± 0.000149**

§ - data represents a concentration greater than the calibration range; data is suspect.

NOTE:
Gray = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology



The JPID ORD level specifies a 1 g/m² starting challenge; this data corresponds to a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID.

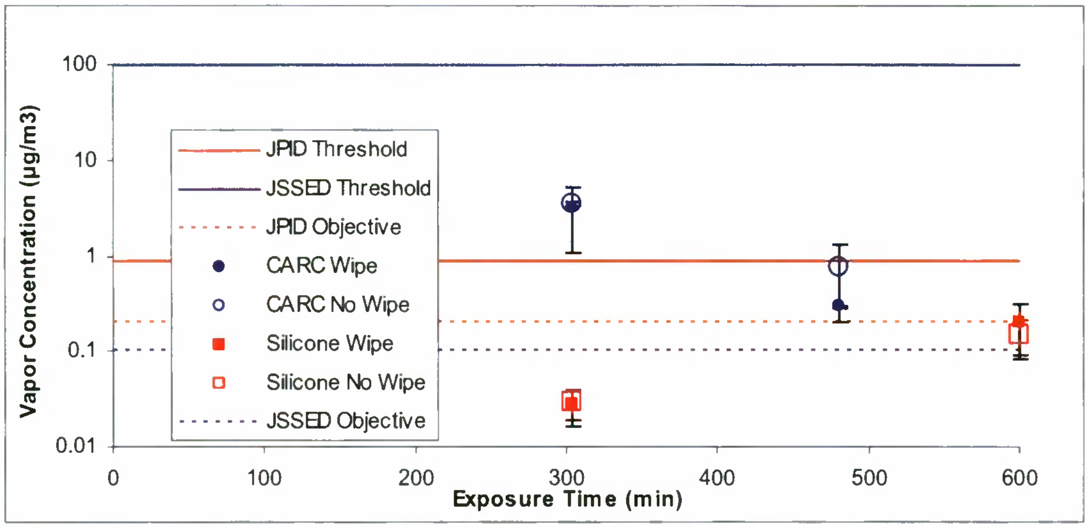
Figure 49. TGD vapor concentration vs. time for glass, polycarbonate, and aluminum.

Table 64. TGD 10 g/m² starting challenge vapor test data for CARC and silicone.

Material	Run	Run Type	Wiped	Exp. Time (min)	Reps	TGD Vapor Concentration (µg/m³)	TGD Vapor Concentration (mg/m³)
CARC	13	Wipe	No	304	5/5	3.72 ± 0.55§	0.003716 ± 0.000550§
	11	Scoping	No	480	3/3	0.75 ± 0.54	0.000748 ± 0.000544
	13	Wipe	**Yes**	**304**	**5/5**	**3.18 ± 2.12**	**0.003184 ± 0.002116**
	11	Scoping	**Yes**	**480**	**2/3**	**0.30 ± 0.01**	**0.000296 ± 0.000008**
Silicone	13	Wipe	No	304	4/5	0.03 ± 0.01	0.000029 ± 0.000011
	13	Wipe	No	600	5/5	0.15 ± 0.06	0.000151 ± 0.000057
	13	Wipe	**Yes**	**304**	**5/5**	**0.03 ± 0.01**	**0.000028 ± 0.000011**
	13	Wipe	**Yes**	**600**	**5/5**	**0.20 ± 0.12**	**0.000201 ± 0.000119**

§ - data represents a concentration greater than the calibration range; data is suspect.

NOTE:
Gray = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology



The JPID ORD level specifies a 1 g/m² starting challenge; this data corresponds to a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID.

Figure 50. TGD vapor concentration vs. time for CARC and silicone.

8.3 Vapor Test Results Compared to ORDs for TGD 10 g/m² Starting Challenge

The specified TGD ORD values for JPID and JSSED are provided in Table 65. The post-decontamination vapor test data for the approximately 10 g/m² TGD starting challenge test was compared to the ORD vapor hazard values and presented in Table 66 and Table 67. Only the JSSED ORD specifies a 10 g/m² starting challenge, therefore, all comparisons to ORD apply only to the JSSED threshold ORD.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The comparisons are only made to the JSSED ORD for this test as the JPID ORD specifies a 1 g/m² starting challenge. The data presented here corresponds to a 10 g/m² starting challenge. The pre-wipe method had little effect on the vapor hazard of silicone. This indicates that absorption time of the agent may be a key factor influencing the long-term hazard of porous materials. The results are summarized in the following list.

- **Wiped and mVHP treated:**
  - **Aluminum** met the JSSED objective ORD after 480 min of decontamination.
  - **CARC** was a factor of 3.0 times the JSSED objective ORD after 480 min of decontamination, but met the JSSED threshold ORD.
  - **Glass** met the JSSED objective ORD after 480 min of decontamination.
  - **Polycarbonate** was a factor of 3.0 times the JSSED objective ORD after 512 min of decontamination, but met the JSSED threshold ORD.
  - **Silicone** was a factor of 2.0 times the JSSED objective ORD after 480 min of decontamination, but met the JSSED threshold ORD. There was less vapor concentration after 300 min of decontamination than 600 min of decontamination.
- **mVHP treatment only (no wiping):**
  - **Aluminum** met the JSSED objective ORD after 480 min of decontamination
  - **CARC** was a **factor** of 7.5 times the JSSED objective ORD after 480 min of decontamination, but met the JSSED threshold ORD.

- **Glass** was a factor of 3.3 times the JSSED objective ORD after 512 min of decontamination, but met the JSSED threshold ORD.
- **Polycarbonate** was a factor of 27 times the JSSED objective ORD after 512 min of decontamination, but met the JSSED threshold ORD.
- **Silicone** was a factor of 1.5 times the JSSED objective ORD after 480 min of decontamination, but met the JSSED threshold ORD. There was less vapor concentration after 300 min of decontamination than 600 min of decontamination.

Table 65. Vapor ORD values for TGD.

ORD	Starting Challenge (g/m^2)	TGD Vapor Concentration	
		($\mu g/m^3$)	(mg/m^3)
JPID Threshold	1	0.87	0.00087
JPID Objective	1	0.2	0.0002
JSSED Threshold	10	100	0.1
JSSED Objective	10	0.1	0.0001

Table 66. TGD 10 g/m^2 starting challenge vapor test results compared to ORDs for pre-wipe and mVHP.

Material	Exp. Time (min)	Wipe	TGD Vapor Concentration (mg/m^3)	JSSED Thresh. Factor	JSSED Obj. Factor
Aluminum	480	Yes	0.0000354 ± 0.0000158	0.00	0.35
CARC	304	Yes	0.0031843 ± 0.0021163	0.03	31.84
	480	Yes	0.0002963 ± 0.0000078	0.00	2.96
Glass	480	Yes	0.0000458 ± 0.0000267	0.00	0.46
	512	Yes	0.0000437 ± 0.0000195	0.00	0.44
Polycarb.	512	Yes	0.0002908 ± 0.0001490	0.00	2.91
Silicone	304	Yes	0.0000275 ± 0.0000108	0.00	0.28
	600	Yes	0.0002011 ± 0.0001187	0.00	2.01

Table 67. TGD 10 g/m^2 starting challenge vapor test results compared to ORDs for mVHP only.

Material	Exp. Time (min)	Wipe	TGD Vapor Concentration (mg/m^3)	JSSED Thresh. Factor	JSSED Obj. Factor
Aluminum	480	No	0.0000542 ± 0.0000193	0.00	0.54
CARC	304	No	0.0037164 ± 0.0005503	0.04	37.16
	480	No	0.0007485 ± 0.0005439	0.01	7.48
Glass	480	No	0.0001825 ± 0.0000175	0.00	1.83
	512	No	0.0003255 ± 0.0003421	0.00	3.25
Polycarb.	512	No	0.0027366 ± 0.0029426	0.03	27.37
Silicone	304	No	0.0000293 ± 0.0000107	0.00	0.29
	600	No	0.000151 ± 0.000057	0.00	1.51

8.4 Contact Test Results for TGD 10 g/m² Starting Challenge

The results of the contact test for 10 g/m² starting challenge of TGD are presented in Table 68 – Table 72 and illustrated in Figure 51 – Figure 55 using semi-log plots. The settings and conditions for each of these experimental runs are listed in Table 11 and Table 12.

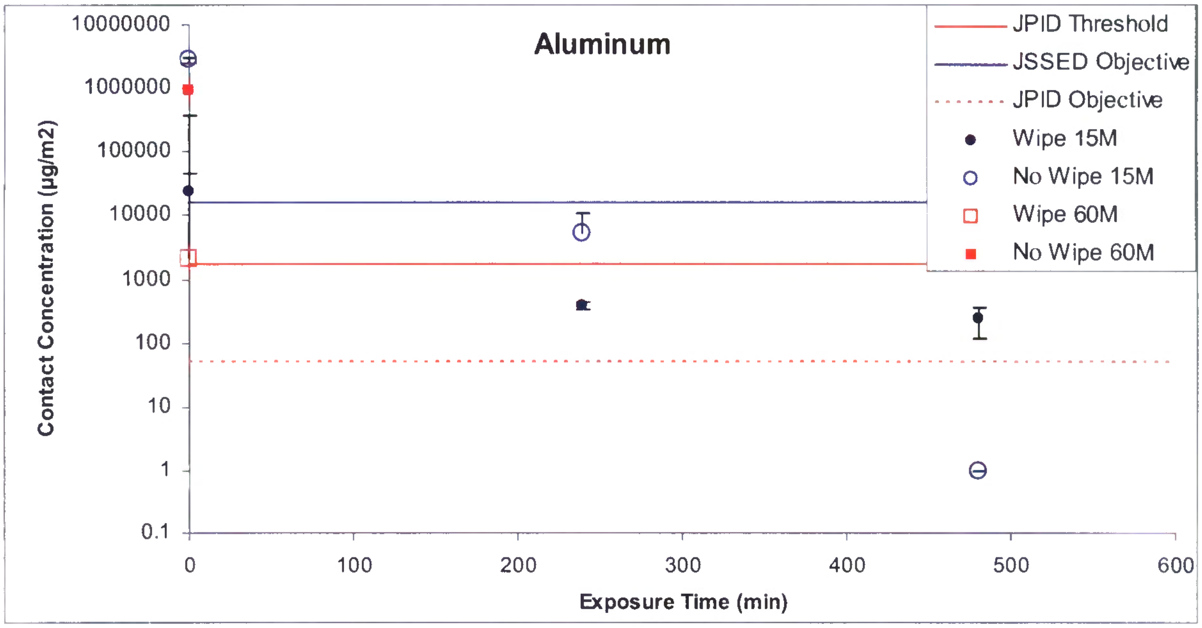
In the following tables, samples that were pre-wiped will be indicated by a "Yes" value in the wiped column. Samples that are pre-wiped and exposed to mVHP are highlighted in yellow. Samples that were only pre-wiped (no mVHP used) are highlighted in gray, and samples that were not wiped (mVHP treatment only) are not highlighted.

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, thus producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table would report a value of zero, a value of 1 μg/m² was assigned so that the data point would be plotted on the graph. There was no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 8.5.

Table 68. TGD 10 g/m² starting challenge contact test results for aluminum.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (μg/m²)	TGD Contact Hazard (mg/m²)
Aluminum	32	No	Ext. Eff.	15M	0	4/4	2799388 ± 258033	2799.388 ± 258.033
Aluminum	11	No	Scoping	15M	239	2/3	5203 ± 6064	5.203 ± 6.064
Aluminum	11	No	Scoping	15M	480	3/3	0 ± 0	0.000 ± 0.000
Aluminum	32	Yes	Ext. Eff.	15M	0	4/4	23548 ± 23778	23.548 ± 23.778
Aluminum	11	Yes	Scoping	15M	239	3/3	391 ± 60	0.391 ± 0.060
Aluminum	11	Yes	Scoping	15M	480	3/3	245 ± 125	0.245 ± 0.125
Aluminum	32	No	Ext. Eff.	60M	0	4/4	955798 ± 372144	955.798 ± 372.144
Aluminum	32	Yes	Ext. Eff.	60M	0	3/4	2196 ± 1350	2.196 ± 1.350

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



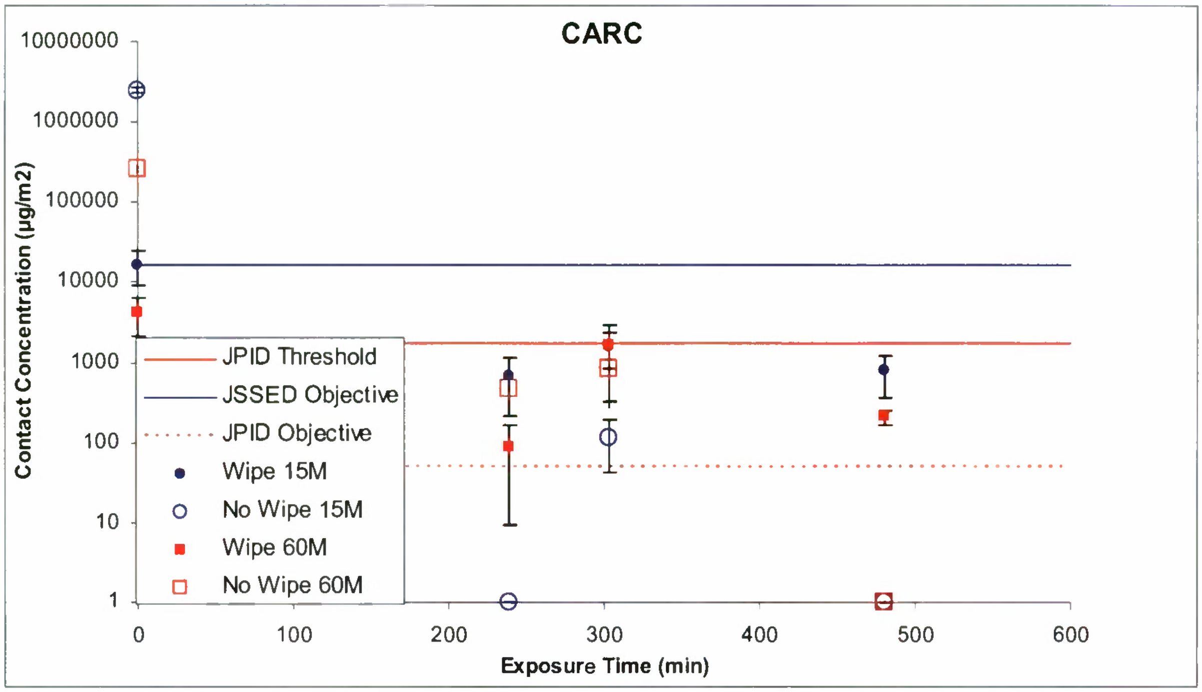
The JPID ORD specifies a 1 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 51. TGD contact concentration vs. time for aluminum (10 g/m² starting challenge).

Table 69. TGD 10 g/m² starting challenge contact test results for CARC.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
CARC	32	No	Ext. Eff.	15M	0	4/4	2509259 ± 206184	2509.259 ± 206.184
CARC	11	No	Scoping	15M	239	3/3	0 ± 0	0.000 ± 0.000
CARC	13	No	Wipe	15M	304	5/5	117 ± 73	0.117 ± 0.073
CARC	11	No	Scoping	15M	480	3/3	0 ± 0	0.000 ± 0.000
CARC	32	Yes	Ext. Eff.	15M	0	4/4	16740 ± 7505	16.740 ± 7.505
CARC	11	Yes	Scoping	15M	239	3/3	684 ± 465	0.684 ± 0.465
CARC	13	Yes	Wipe	15M	304	4/5	1589 ± 745	1.589 ± 0.745
CARC	11	Yes	Scoping	15M	480	3/3	783 ± 426	0.783 ± 0.426
CARC	32	No	Ext. Eff.	60M	0	3/4	258124 ± 27007	258.124 ± 27.007
CARC	11	No	Scoping	60M	239	3/3	464 ± 125	0.464 ± 0.125
CARC	13	No	Wipe	60M	304	5/5	824 ± 538	0.824 ± 0.538
CARC	11	No	Scoping	60M	480	3/3	0 ± 0	0.000 ± 0.000
CARC	32	Yes	Ext. Eff.	60M	0	4/4	4251 ± 2109	4.251 ± 2.109
CARC	11	Yes	Scoping	60M	239	3/3	87 ± 78	0.087 ± 0.078
CARC	13	Yes	Wipe	60M	304	5/5	1626 ± 1303	1.626 ± 1.303
CARC	11	Yes	Scoping	60M	480	3/3	212 ± 45	0.212 ± 0.045

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



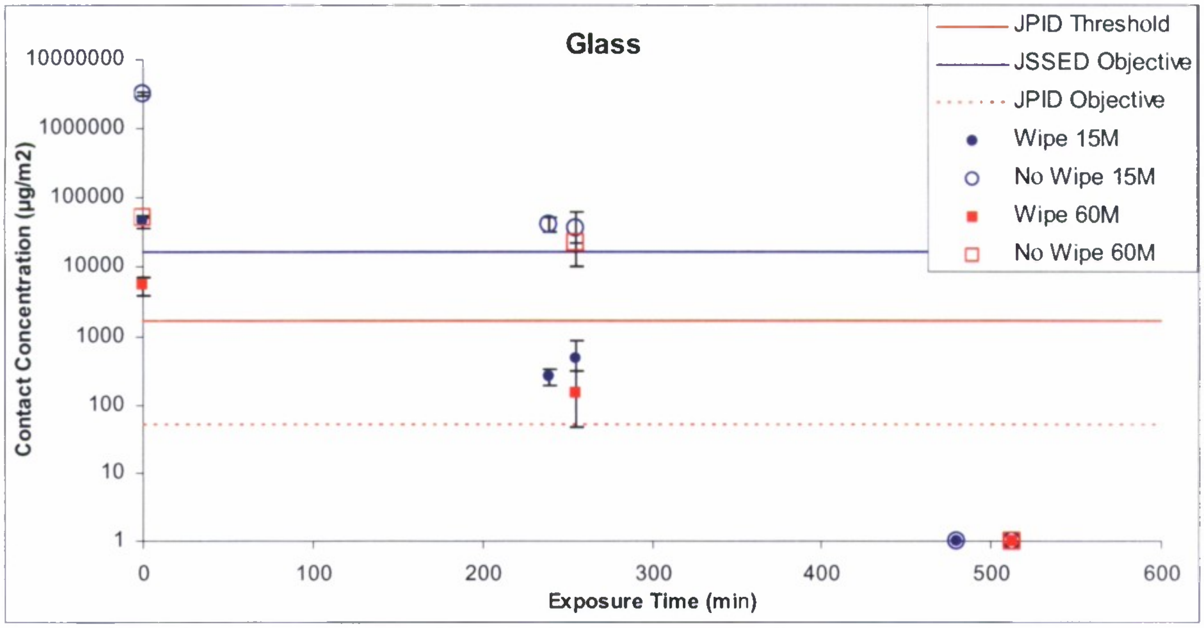
Only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 52. TGD contact concentration vs. time for CARC (10 g/m² starting challenge).

Table 70. TGD 10 g/m² starting challenge contact test results for glass.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
Glass	32	No	Ext. Eff.	15M	0	3/4	3173999 ± 201287	3173.999 ± 201.287
Glass	11	No	Scoping	15M	239	3/3	42010 ± 10638	42.010 ± 10.638
Glass	12	No	Wipe	15M	255	4/4	36701 ± 26352	36.701 ± 26.352
Glass	11	No	Scoping	15M	480	3/3	0 ± 0	0.000 ± 0.000
Glass	12	No	Wipe	15M	512	3/4	0 ± 0	0.000 ± 0.000
Glass	32	Yes	Ext. Eff.	15M	0	3/4	46398 ± 9245	46.398 ± 9.245
Glass	11	Yes	Scoping	15M	239	3/3	262 ± 66	0.262 ± 0.066
Glass	12	Yes	Wipe	15M	255	4/4	468 ± 419	0.468 ± 0.419
Glass	11	Yes	Scoping	15M	480	3/3	0 ± 0	0.000 ± 0.000
Glass	12	Yes	Wipe	15M	512	3/4	0 ± 0	0.000 ± 0.000
Glass	32	No	Ext. Eff.	60M	0	4/4	53025 ± 35567	53.025 ± 35.567
Glass	12	No	Wipe	60M	255	4/4	22968 ± 15513	22.968 ± 15.513
Glass	12	No	Wipe	60M	512	3/4	0 ± 0	0.000 ± 0.000
Glass	32	Yes	Ext. Eff.	60M	0	4/4	5501 ± 1491	5.501 ± 1.491
Glass	12	Yes	Wipe	60M	255	4/4	153 ± 159	0.153 ± 0.159
Glass	12	Yes	Wipe	60M	512	4/4	0 ± 0	0.000 ± 0.000

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



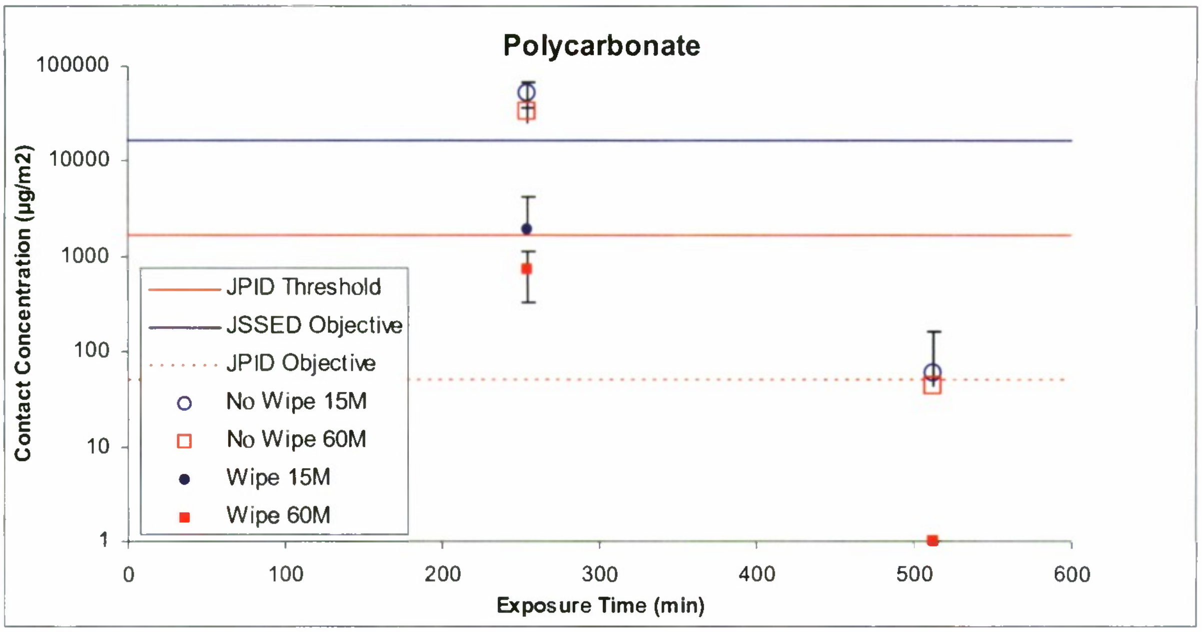
Only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 53. TGD contact concentration vs. time for Glass (10 g/m² starting challenge).

Table 71. TGD 10 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
Polycarb.	12	No	Wipe	15M	255	4/4	51656 ± 14962	51.656 ± 14.962
Polycarb.	12	No	Wipe	15M	512	3/4	60 ± 105	0.060 ± 0.105
Polycarb.	12	Yes	Wipe	15M	255	3/4	1934 ± 2258	1.934 ± 2.258
Polycarb.	12	Yes	Wipe	15M	512	3/4	0 ± 0	0.000 ± 0.000
Polycarb.	12	No	Wipe	60M	255	4/4	33432 ± 8036	33.432 ± 8.036
Polycarb.	12	No	Wipe	60M	512	3/4	43 ± 74	0.043 ± 0.074
Polycarb.	12	Yes	Wipe	60M	255	4/4	725 ± 396	0.725 ± 0.396
Polycarb.	12	Yes	Wipe	60M	512	3/4	0 ± 0	0.000 ± 0.000

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



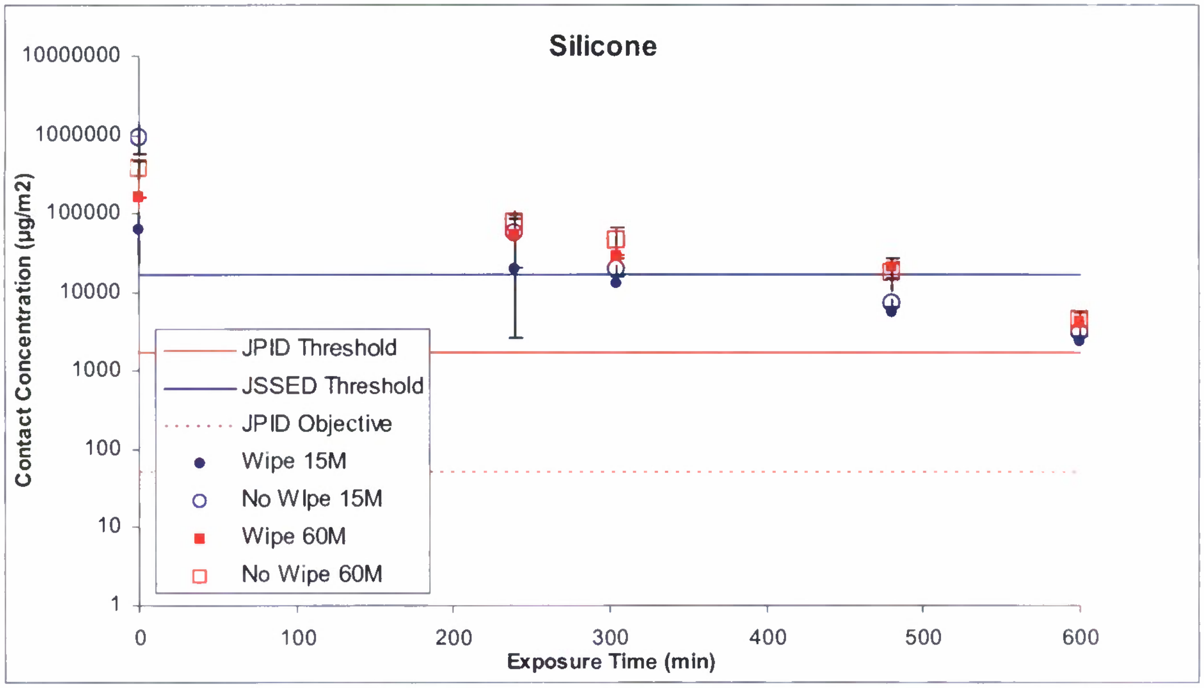
Only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 54. TGD contact concentration vs. time for polycarbonate (10 g/m² starting challenge).

Table 72. TGD 10 g/m² starting challenge contact test results for silicone.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
Silicone	32	No	Ext. Eff.	15M	0	4/4	938148 ± 373327	938.148 ± 373.327
Silicone	11	No	Scoping	15M	239	3/3	54989 ± 52354	54.989 ± 52.354
Silicone	13	No	Wipe	15M	304	4/5	19255 ± 3006	19.255 ± 3.006
Silicone	11	No	Scoping	15M	480	3/3	7221 ± 689	7.221 ± 0.689
Silicone	13	No	Wipe	15M	600	4/5	3091 ± 254	3.091 ± 0.254
Silicone	32	Yes	Ext. Eff.	15M	0	4/4	63840 ± 39355	63.840 ± 39.355
Silicone	11	Yes	Scoping	15M	239	3/3	19388 ± 3362	19.388 ± 3.362
Silicone	13	Yes	Wipe	15M	304	5/5	13170 ± 1818	13.170 ± 1.818
Silicone	11	Yes	Scoping	15M	480	3/3	5644 ± 772	5.644 ± 0.772
Silicone	13	Yes	Wipe	15M	600	5/5	2401 ± 281	2.401 ± 0.281
Silicone	32	No	Ext. Eff.	60M	0	4/4	372765 ± 98268	372.765 ± 98.268
Silicone	11	No	Scoping	60M	239	3/3	79242 ± 15445	79.242 ± 15.445
Silicone	13	No	Wipe	60M	304	4/5	46644 ± 19345	46.644 ± 19.345
Silicone	11	No	Scoping	60M	480	3/3	17199 ± 6733	17.199 ± 6.733
Silicone	13	No	Wipe	60M	600	4/5	4421 ± 1095	4.421 ± 1.095
Silicone	32	Yes	Ext. Eff.	60M	0	4/4	159517 ± 32552	159.517 ± 32.552
Silicone	11	Yes	Scoping	60M	239	3/3	53500 ± 1697	53.500 ± 1.697
Silicone	13	Yes	Wipe	60M	304	5/5	28140 ± 5828	28.140 ± 5.828
Silicone	11	Yes	Scoping	60M	480	3/3	20863 ± 546	20.863 ± 0.546
Silicone	13	Yes	Wipe	60M	600	5/5	4213 ± 1878	4.213 ± 1.878

NOTE: Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology



Only the JSSED Threshold level specifies a 10 g/m² starting challenge. The JPID threshold and objective levels are drawn on this figure, but DO NOT APPLY to this starting challenge level. These results correspond to a starting challenge 10 times greater than the starting challenge for JPID. The data points for an exposure time of zero correspond to only pre-wiping the sample. Because this is a semi-log plot, data with a value of zero cannot be plotted. For visualization, data with a value of zero in the table is assigned a value of 1 µg/m² so that it will be plotted in the figure.

Figure 55. TGD contact concentration vs. time for silicone (10 g/m² starting challenge).

Table 73. TGD 10 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
Aluminum	32	No	Ext. Eff.	RES	0	4/4	12515 ± 3330	12.515 ± 3.330
Aluminum	11	No	Scoping	RES	239	2/3	6 ± 7	0.006 ± 0.007
Aluminum	11	No	Scoping	RES	480	3/3	0 ± 0	0.000 ± 0.000
Aluminum	**32**	**Yes**	**Ext. Eff.**	**RES**	**0**	**4/4**	**1770 ± 873**	**1.770 ± 0.873**
Aluminum	11	Yes	Scoping	RES	239	3/3	269 ± 153	0.269 ± 0.153
Aluminum	11	Yes	Scoping	RES	480	3/3	216 ± 196	0.216 ± 0.196
CARC	32	No	Ext. Eff.	RES	0	4/4	7841 ± 4346	7.841 ± 4.346
CARC	11	No	Scoping	RES	239	3/3	56 ± 4	0.056 ± 0.004
CARC	13	No	Wipe	RES	304	5/5	28 ± 14	0.028 ± 0.014
CARC	11	No	Scoping	RES	480	3/3	5 ± 1	0.005 ± 0.001
CARC	**32**	**Yes**	**Ext. Eff.**	**RES**	**0**	**¾**	**2305 ± 222**	**2.305 ± 0.222**
CARC	11	Yes	Scoping	RES	239	3/3	2 ± 1	0.002 ± 0.001
CARC	13	Yes	Wipe	RES	304	5/5	41 ± 53	0.041 ± 0.053
CARC	11	Yes	Scoping	RES	480	2/3	0 ± 0	0.000 ± 0.000
Glass	32	No	Ext. Eff.	RES	0	4/4	687 ± 152	0.687 ± 0.152
Glass	11	No	Scoping	RES	239	2/3	86 ± 1	0.086 ± 0.001
Glass	12	No	Wipe	RES	255	4/4	29 ± 13	0.029 ± 0.013
Glass	11	No	Scoping	RES	480	3/3	0 ± 0	0.000 ± 0.000

Table 73. TGD 10 g/m² starting challenge contact test residual agent results for all materials (continued).

Material	Run	Wipe	Run Type	Test Set	Exp. Time (min)	Reps	TGD Contact Hazard (µg/m²)	TGD Contact Hazard (mg/m²)
Glass	12	No	Wipe	RES	512	3/4	0 ± 0	0.000 ± 0.000
Glass	32	Yes	Ext. Eff.	RES	0	4/4	1275 ± 387	1.275 ± 0.387
Glass	11	Yes	Scoping	RES	239	3/3	85 ± 76	0.085 ± 0.076
Glass	12	Yes	Wipe	RES	255	3/4	0 ± 1	0.000 ± 0.001
Glass	11	Yes	Scoping	RES	480	3/3	0 ± 0	0.000 ± 0.000
Glass	12	Yes	Wipe	RES	512	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	12	No	Wipe	RES	255	4/4	29 ± 2	0.029 ± 0.002
Polycarb.	12	No	Wipe	RES	512	4/4	102 ± 119	0.102 ± 0.119
Polycarb.	12	Yes	Wipe	RES	255	4/4	96 ± 116	0.096 ± 0.116
Polycarb.	12	Yes	Wipe	RES	512	2/4	0 ± 0	0.000 ± 0.000
Silicone	32	No	Ext. Eff.	RES	0	3/4	1884213 ± 90977	1884.213 ± 90.977
Silicone	11	No	Scoping	RES	239	2/3	2 ± 0	0.002 ± 0.000
Silicone	13	No	Wipe	RES	304	4/5	1 ± 0	0.001 ± 0.000
Silicone	11	No	Scoping	RES	480	2/3	1 ± 0	0.001 ± 0.000
Silicone	13	No	Wipe	RES	600	4/5	337 ± 52	0.337 ± 0.052
Silicone	32	Yes	Ext. Eff.	RES	0	4/4	1248295 ± 151220	1248.295 ± 151.220
Silicone	11	Yes	Scoping	RES	239	3/3	1 ± 0	0.001 ± 0.000
Silicone	13	Yes	Wipe	RES	304	5/5	1 ± 0	0.001 ± 0.000
Silicone	11	Yes	Scoping	RES	480	2/3	1 ± 0	0.001 ± 0.000
Silicone	13	Yes	Wipe	RES	600	4/5	432 ± 31	0.432 ± 0.031

NOTE:
Yellow = Combination of mVHP and pre-wipe technology
Gray = Exclusively pre-wipe technology
White = Exclusively mVHP technology

In addition to the 15M and 60M test specified in the TOP, a residual extraction analysis was performed on each contact sample (Table 73). The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, these values under estimated the actual residual agent present. The acquisition of these results was not specified in the TOP or the ORDs, and therefore, the results have no comparison to ORD values.

8.5 Contact Test Results Compared to ORDs for TGD 10 g/m² Starting Challenge

The specified TGD ORD values for JPID and JSSED are provided in Table 74. The post-decontamination contact test data for the approximately 10 g/m² TGD starting challenge test is compared to the ORD contact hazard values and presented in Table 74.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The comparisons are only made to the JSSED ORD for this test, as the JPID ORD specifies a 1 g/m² starting challenge. The data presented here corresponds to a 10 g/m² starting challenge. Table 75 corresponds to the resulting contact hazard after using the wipe technology (mVHP is not used). The results are summarized in the following list.

- **Aluminum** was a factor of 1.4 times the JSSED objective ORD after using the pre-wipe method.
- **CARC** met the JSSED objective ORD after using the pre-wipe method.
- **Glass** was a factor of 2.8 times the JSSED objective ORD after using the pre-wipe method.
- **Silicone** was a factor of 3.8 times the JSSED objective ORD after using the pre-wipe method. The 60M test exhibits a higher hazard than the 15M test.

This data indicates that the pre-wipe method reduced the TGD concentration detectible by the contact hazard test to less than 1 g/m^2 (1000 mg/m^2) for aluminum, CARC, glass, and silicone. This is a good indication that the 1 g/m^2 starting challenge data may be comparable to the JSSED ORD, which specifies a 10 g/m^2 starting challenge, if the pre-wipe method is used. This effect has not yet been proven.

Table 76 corresponds to the resulting contact hazard after using the pre-wipe technology then applying mVHP. The results are provided in the following list.

- **Aluminum** met the JSSED objective ORD after 239 min of decontamination.
- **CARC** met the JSSED objective ORD after 239 min of decontamination.
- **Glass** met the JSSED objective ORD after 239 min of decontamination.
- **Polycarbonate** met the JSSED objective ORD after 239 min of decontamination.
- **Silicone** met the JSSED objective ORD after 600 min of decontamination.

Table 77 corresponds to the resulting contact hazard after using only the mVHP technology. The results are provided in the following list.

- **Aluminum** met the JSSED objective ORD after 239 min of decontamination.
- **CARC** met the JSSED objective ORD after 239 min of decontamination.
- **Glass** met the JSSED objective ORD after 512 min of decontamination.
- **Polycarbonate** met the JSSED objective ORD after 512 min of decontamination.
- **Silicone** met the JSSED objective ORD after 600 min of decontamination.

Table 74. Contact ORD values for TGD.

ORD	Starting Challenge (g/m^2)	TGD Contact Concentration	
		(µg/m^2)	(mg/m^2)
JPID Threshold	1	1700	1.7
JPID Objective	1	0* (50)	0.0* (0.05)
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	16700	16.7

* This value was set as 0.0 mg/m^2 in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m^2 (when rounded to the presented accuracy would return a result of 0.1 mg/m^2) fail the JPID objective level.

Table 75. Evaluation of pre-wipe method (exclusively) on TGD 10 g/m² starting challenge.

Material	Wipe	Exp.	Test Set	TGD Contact Hazard (mg/m²)	JSSED Obj. Factor
Aluminum	Yes	0	15M	23.548 ± 23.778	1.41
			60M	2.196 ± 1.350	0.13
CARC	Yes	0	15M	16.740 ± 7.505	1.00
			60M	4.251 ± 2.109	0.25
Glass	Yes	0	15M	46.398 ± 9.245	2.78
			60M	5.501 ± 1.491	0.33
Silicone	Yes	0	15M	63.840 ± 39.355	3.82
			60M	159.517 ± 32.552	9.55

Table 76. Evaluation of contact test results for mVHP with pre-wipe on TGD 10 g/m² starting challenge.

Material	Wipe	Exp. Time (min)	Test Set	TGD Contact Hazard (mg/m²)	JSSED Obj. Factor
Aluminum	Yes	239	15M	0.391 ± 0.060	0.02
		480	15M	0.245 ± 0.125	0.01
CARC	Yes	239	15M	0.684 ± 0.465	0.04
			60M	0.087 ± 0.078	0.01
		304	15M	1.589 ± 0.745	0.10
			60M	1.626 ± 1.303	0.10
		480	15M	0.783 ± 0.426	0.05
			60M	0.212 ± 0.045	0.01
Glass	Yes	239	15M	0.262 ± 0.066	0.02
		255	15M	0.468 ± 0.419	0.03
			60M	0.153 ± 0.159	0.01
		480	15M	0.000 ± 0.000	0.00
		512	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Polycarb.	Yes	255	15M	1.934 ± 2.258	0.12
			60M	0.725 ± 0.396	0.04
		512	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Silicone	Yes	239	15M	19.388 ± 3.362	1.16
			60M	53.500 ± 1.697	3.20
		304	15M	13.170 ± 1.818	0.79
			60M	28.140 ± 5.828	1.69
		480	15M	5.644 ± 0.772	0.34
			60M	20.863 ± 0.546	1.25
		600	15M	2.401 ± 0.281	0.14
			60M	4.213 ± 1.878	0.25

Table 77. Evaluation of mVHP (exclusively) on TGD 10 g/m² starting challenge.

Material	Wipe	Exp. Time (min)	Test Set	TGD Contact Hazard (mg/m²)	JSSED Objective Factor
Aluminum	No	239	15M	5.203 ± 6.064	0.31
		480	15M	0.000 ± 0.000	0.00
CARC	No	239	15M	0.000 ± 0.000	0.00
			60M	0.464 ± 0.125	0.03
		304	15M	0.117 ± 0.073	0.01
			60M	0.824 ± 0.538	0.05
		480	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Glass	No	255	15M	36.701 ± 26.352	2.20
			60M	22.968 ± 15.513	1.38
		512	15M	0.000 ± 0.000	0.00
			60M	0.000 ± 0.000	0.00
Polycarb.	No	255	15M	51.656 ± 14.962	3.09
			60M	33.432 ± 8.036	2.00
		512	15M	0.060 ± 0.105	0.00
			60M	0.043 ± 0.074	0.00
Silicone	No	239	15M	54.989 ± 52.354	3.29
			60M	79.242 ± 15.445	4.75
		304	15M	19.255 ± 3.006	1.15
			60M	46.644 ± 19.345	2.79
		480	15M	7.221 ± 0.689	0.43
			60M	17.199 ± 6.733	1.03
		600	15M	3.091 ± 0.254	0.19
			60M	4.421 ± 1.095	0.26

9. TEST RESULTS AND DISCUSSION: VX 1 g/m² TEST

9.1 Test Summary for VX 1 g/m² Starting Challenge

The mVHP testing starting challenge was approximately 1 g/m², applied as three 0.5 µL drops of VX from a repeater syringe. The error bars presented in the tables and figures represent one standard deviation of the data. For each of the figures the ORD values are drawn as solid lines. These values are reviewed in Table 5. Any data point above a solid line indicates that it did not meet the ORD value. For VX the objective values of JPID and JSSED are identical, therefore, they are drawn as one line in each figure.

The conditions for each experimental run and exposure time are listed in Table 11 and Table 12. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

Run 14 did not use V-to-G conversion pads for the vapor test, thus the instruments could not detect the agent. This vapor data has been omitted from this report.

The VX sample CCV failures posed quite a challenge for the analytical staff. Run 17R was performed using methylene chloride rather than ethyl acetate to determine whether the problem was associated to solvent. The methylene chloride samples had more CCV failures than the ethyl acetate samples.

A limited set of 10 g/m² VX starting challenge data was acquired to evaluate the performance of the pre-wipe technology and serve as a scoping test. Results determined from the pre-wipe method can most likely be improved because there was no optimization of VX.

The ORD levels for VX were at least an order of magnitude lower than any other agent. The sensitivity required to detect the ORD levels were at the detection limits of the instruments and methods used. For this reason, there were a significant number of CCV failures. A significant portion of this data did not meet the quality control criteria due to the inability to maintain the instrumentation within specifications. In these cases, a single-point calibration correction was used to recover the data, as discussed in Section 2.12.3. These data points are flagged as suspect data in each table. This discussion is continued in Section 11.3.

A limited set of 10 g/m² starting challenge data with and with out the pre-wipe was acquired.

9.2 Vapor Test Results for VX 1 g/m² Starting Challenge

The results of the vapor test for 1 g/m² starting challenge of VX are presented in Table 78 – Table 81 and illustrated in Figure 56 – Figure 59. Four replicate coupons were measured for scoping runs, and five replicates were measured for efficacy runs, using each material with at least two exposure times each. These results are numerically compared to the ORDs in Section 9.3.

Table 78. VX 1 g/m² starting challenge vapor results for glass and polycarbonate.

Material	Run	Run Type	Exp. Time (min)	Reps	VX Vapor Concentration (µg/m³)	VX Vapor Concentration (mg/m³)
Glass	16	Efficacy	241	5/5	0.164 ± 0.075	0.000164 ± 0.000075
Glass	34	Efficacy	360	4/4	0.086 ± 0.012	0.000086 ± 0.000012
Glass	30	Efficacy	360	5/5	0.205 ± 0.057	0.000205 ± 0.000057
Glass	16	Efficacy	622	5/5	0.005 ± 0.001	0.000005 ± 0.000001
Polycarb.	16	Efficacy	241	5/5	0.033 ± 0.029	0.000033 ± 0.000029
Polycarb.	34	Efficacy	360	4/4	0.053 ± 0.014	0.000053 ± 0.000014
Polycarb.	30	Efficacy	360	4/5	0.165 ± 0.061	0.000165 ± 0.000061
Polycarb.	16	Efficacy	622	5/5	0.003 ± 0.002	0.000003 ± 0.000002

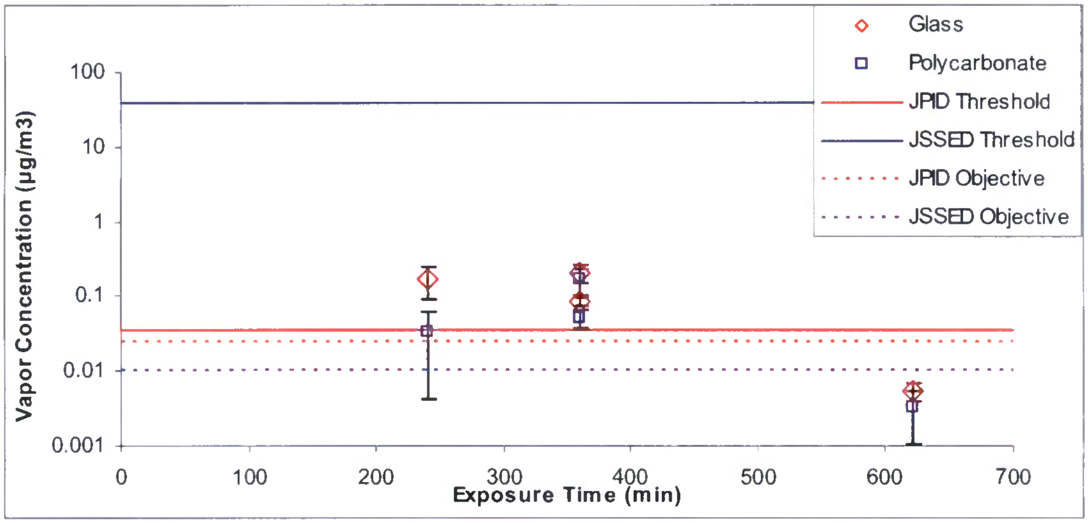


Figure 56. VX vapor concentration vs. time for glass and polycarbonate.

Table 79. VX 1 g/m² starting challenge vapor results for AF topcoat and CARC.

Material	Run	Run Type	Exp. Time (min)	Reps	VX Vapor Concentration (µg/m³)	VX Vapor Concentration (mg/m³)
AF topcoat	17	Efficacy	354	5/5	0.130 ± 0.024	0.000130 ± 0.000024
AF topcoat	17	Efficacy	595	5/5	0.023 ± 0.003‡	0.000023 ± 0.000003‡
CARC	17	Efficacy	354	5/5	0.036 ± 0.013‡	0.000036 ± 0.000013‡
CARC	30	Efficacy	360	5/5	0.104 ± 0.027	0.000104 ± 0.000027
CARC	34	Efficacy	360	3/4	0.075 ± 0.056	0.000075 ± 0.000056
CARC	17	Efficacy	595	5/5	0.028 ± 0.006	0.000028 ± 0.000006

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

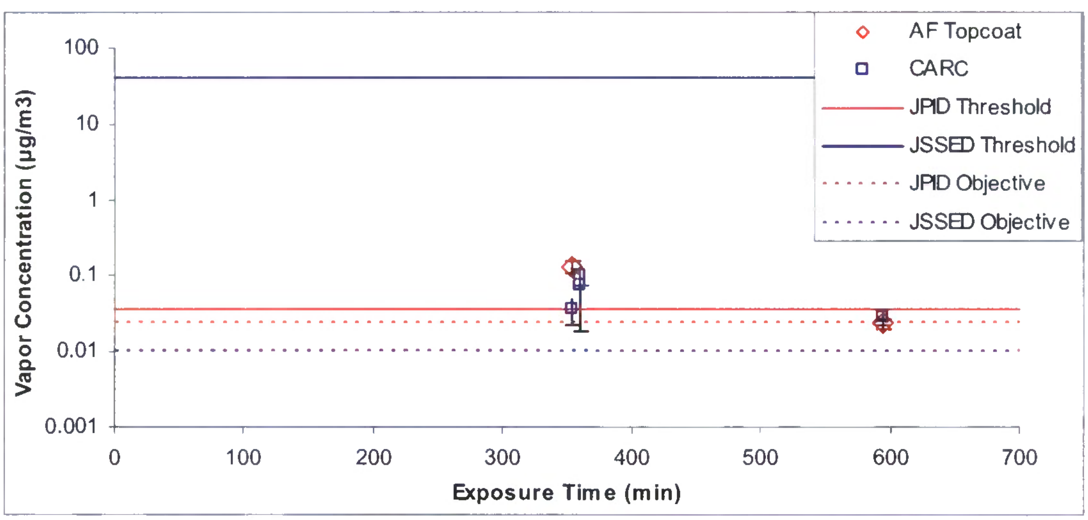


Figure 57. VX vapor concentration vs. time for AF topcoat and CARC.

Table 80. VX 1 g/m² starting challenge vapor results for silicone and Viton.

Material	Run	Run Type	Exp. Time (min)	Reps	VX Vapor Concentration (µg/m³)	VX Vapor Concentration (mg/m³)
Silicone	17	Efficacy	354	5/5	0.087 ± 0.014	0.000087 ± 0.000014
Silicone	30	Efficacy	360	5/5	0.072 ± 0.030	0.000072 ± 0.000030
Silicone	34	Efficacy	360	4/4	0.010 ± 0.002	0.000010 ± 0.000002
Silicone	17	Efficacy	595	5/5	0.030 ± 0.006‡	0.000030 ± 0.000006‡
Viton	17	Efficacy	354	5/5	1.378 ± 0.108‡	0.001378 ± 0.000108‡
Viton	17	Efficacy	595	5/5	0.544 ± 0.043‡	0.000544 ± 0.000043‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

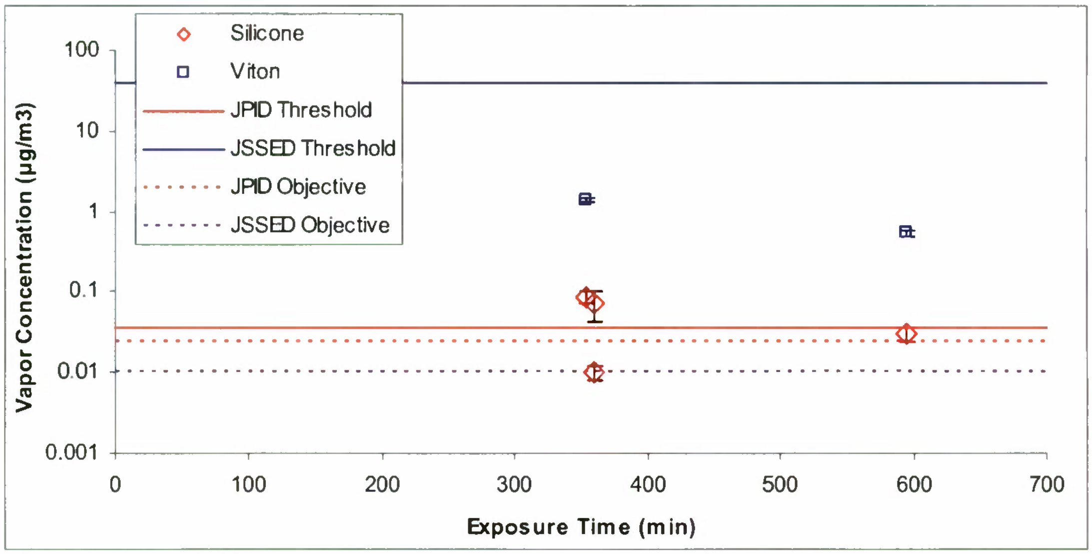


Figure 58. VX vapor concentration vs. time for silicone and Viton.

Table 81. VX 1 g/m² starting challenge vapor results for aluminum and Kapton.

Material	Run	Run Type	Exp. Time (min)	Reps	VX Vapor Concentration (µg/m³)	VX Vapor Concentration (mg/m³)
Aluminum	16	Efficacy	241	5/5	0.029 ± 0.016	0.000029 ± 0.000016
Aluminum	16	Efficacy	622	5/5	0.009 ± 0.007	0.000009 ± 0.000007
Kapton	16	Efficacy	241	5/5	0.018 ± 0.008	0.000018 ± 0.000008
Kapton	16	Efficacy	622	5/5	0.003 ± 0.002	0.000003 ± 0.000002

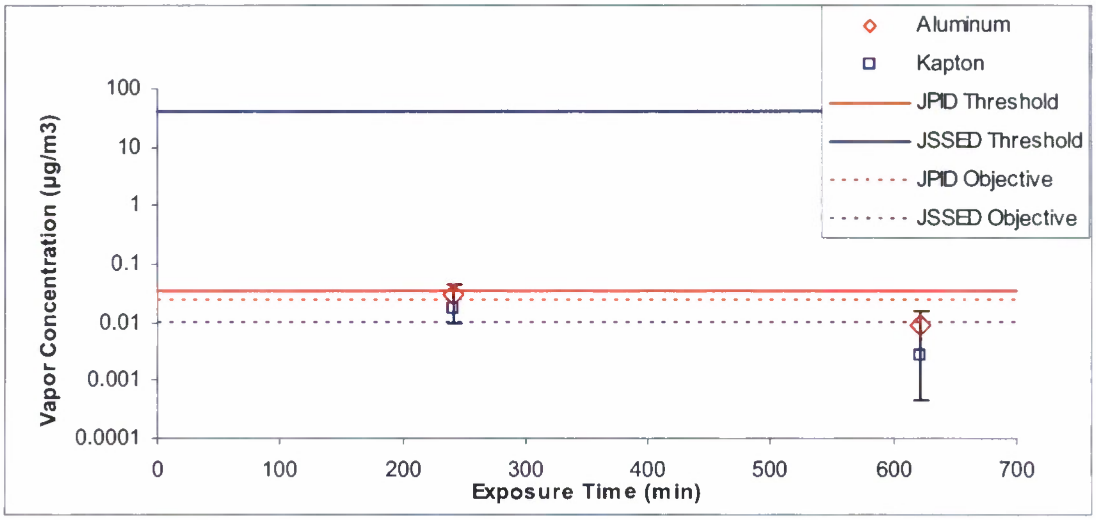


Figure 59. VX vapor concentration vs. time for aluminum and Kapton.

9.3 Vapor Test Results Compared to ORDs for VX 1 g/m^2 Starting Challenge

The specified VX ORD values for JPID and JSSED are provided in Table 82. The post-decontamination vapor test data for the approximately 1 g/m^2 VX starting challenge test was directly compared to the ORD vapor hazard values and presented in Table 83.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value $\leq$1.0 passes the ORD; a value >1.0 fails to meet the ORD. The Table 83 results for a 1 g/m^2 starting challenge of VX are provided in the following list.

- **AF topcoat** met the JPID objective ORD after 595 min of decontamination.
- **Aluminum** met the JPID objective ORD after 622 min of decontamination.
- **CARC** was a factor of 12 times the JPID objective ORD after 595 min of decontamination, but met the JPID and JSSED threshold ORDs.
- **Glass** met the JPID objective ORD after 622 min of decontamination.
- **Kapton** met the JPID objective ORD after 241 min of decontamination.
- **Polycarbonate** met the JPID objective ORD after 622 min of decontamination.
- **Silicone** was a factor of 1.25 times the JPID objective ORD after 595 min of decontamination, but met the JPID and JSSED threshold ORDs.
- **Viton** was a factor of 22 times the JPID objective ORD after 595 min of decontamination, but met the JSSED threshold ORD. This value was an over estimate due to interfering compounds emitted by Viton.

The JSSED ORD values specify a 10 g/m^2 starting challenge. The data presented here corresponds to a 1 g/m^2 starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m^2 to 1 g/m^2 for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m^2 data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m^2 data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 82. Vapor ORD values for VX.

ORD	Starting Challenge (g/m^2)	VX Vapor Concentration ($\mu g/m^3$)	VX Vapor Concentration (mg/m^3)
JPID Threshold	1	0.036	0.000036
JPID Objective	1	0.024	0.000024
JSSED Threshold	10	40	0.04
JSSED Objective	10	0.01	0.00001

Table 83. Vapor efficacy of mVHP on VX: 1 g/m^2 starting challenge.

Material	Exp. Time (min)	VX Vapor Concentration (mg/m^3)	JPID Thresh. Factor	JSSED Thresh. Factor	JPID Obj. Factor	JSSED Obj. Factor
AF topcoat	354	0.000130 ± 0.000024	3.62	0.00	5.43	13.04
	595	0.000023 ± 0.000003‡	0.65‡	0.00‡	0.97‡	2.32‡
Aluminum	241	0.000029 ± 0.000016	0.82	0.00	1.23	2.95
	622	0.000009 ± 0.000007	0.26	0.00	0.39	0.93
CARC	354	0.000036 ± 0.000013‡	0.99‡	0.00‡	1.48‡	3.56‡
	360	0.000104 ± 0.000027	2.89	0.00	4.33	10.39
	360	0.000075 ± 0.000056	2.09	0.00	3.13	7.52
	595	0.000028 ± 0.000006	0.79	0.00	1.18	2.83
Glass	241	0.000164 ± 0.000075	4.56	0.00	6.84	16.42
	360	0.000086 ± 0.000012	2.39	0.00	3.58	8.60
	360	0.000205 ± 0.000057	5.70	0.01	8.54	20.50
	622	0.000005 ± 0.000001	0.15	0.00	0.23	0.54
Kapton	241	0.000018 ± 0.000008	0.49	0.00	0.73	1.76
	622	0.000003 ± 0.000002	0.08	0.00	0.11	0.27
Polycarb.	241	0.000033 ± 0.000029	0.91	0.00	1.36	3.27
	360	0.000053 ± 0.000014	1.47	0.00	2.20	5.28
	360	0.000165 ± 0.000061	4.60	0.00	6.89	16.55
	622	0.000003 ± 0.000002	0.09	0.00	0.14	0.33
Silicone	354	0.000087 ± 0.000014	2.40	0.00	3.61	8.66
	360	0.000072 ± 0.000030	2.00	0.00	3.00	7.20
	360	0.000010 ± 0.000002	0.28	0.00	0.41	0.99
	595	0.000030 ± 0.000006‡	0.83‡	0.00‡	1.25‡	3.00‡
Viton *	354	0.001378 ± 0.000108‡	38.28‡	0.03‡	57.42‡	137.82‡
	595	0.000544 ± 0.000043‡	15.10‡	0.01‡	22.65‡	54.37‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.
*Viton emits an interfering compound that artificially inflates these results.

9.4 Contact Test Results for VX 1 g/m² Starting Challenge

The results of the contact test for VX 1 g/m² starting challenge are presented in Table 84 – Table 91 and illustrated in Figure 60 – Figure 67 using semi-log plots. The contact test analysis methods are discussed in Section 2.10.1.

There were four types of runs used in the contact test analysis: baseline, extraction efficiency (ext. eff.), scoping, and efficacy (see Section 2.15). The baseline and extraction efficiency runs used no decontaminant. The baseline and extraction efficiency runs are highlighted in gray in Table 84 – Table 91 because they do not represent decontamination efficacy data (i.e., CT H_2O_2 = 0). They provide a baseline for the response for natural agent weathering at ambient conditions (i.e., no mVHP treatment). For each of the graphs, the "baseline" data includes both the baseline run and the extraction efficiency run (used for exposure time zero). In a similar fashion, the "efficacy" data presented in the graphs includes both efficacy and scoping data (if available).

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, thus producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table would report a value of zero, a value of 1 µg/m² was assigned so that the data point would be plotted on the graph. There is no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 9.5.

Table 84. VX 1 g/m² starting challenge contact test results for AF topcoat.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
AF topcoat	35	Ext. Eff.	15M	0	4/4	320402 ± 125035	320.402 ± 125.035
AF topcoat	15	Baseline	15M	59	3/3	249212 ± 61342	249.212 ± 61.342
AF topcoat	15	Baseline	15M	272	3/3	80198 ± 79047	80.198 ± 79.047
AF topcoat	17	Efficacy	15M	354	5/5	108 ± 79	0.108 ± 0.079
AF topcoat	35	Ext. Eff.	60M	0	4/4	116029 ± 15908	116.029 ± 15.908
AF topcoat	15	Baseline	60M	59	3/3	82712 ± 51843	82.712 ± 51.843
AF topcoat	15	Baseline	60M	272	3/3	111069 ± 34191	111.069 ± 34.191
AF topcoat	17	Efficacy	60M	354	1/5	17 ± 0	0.017 ± 0.000

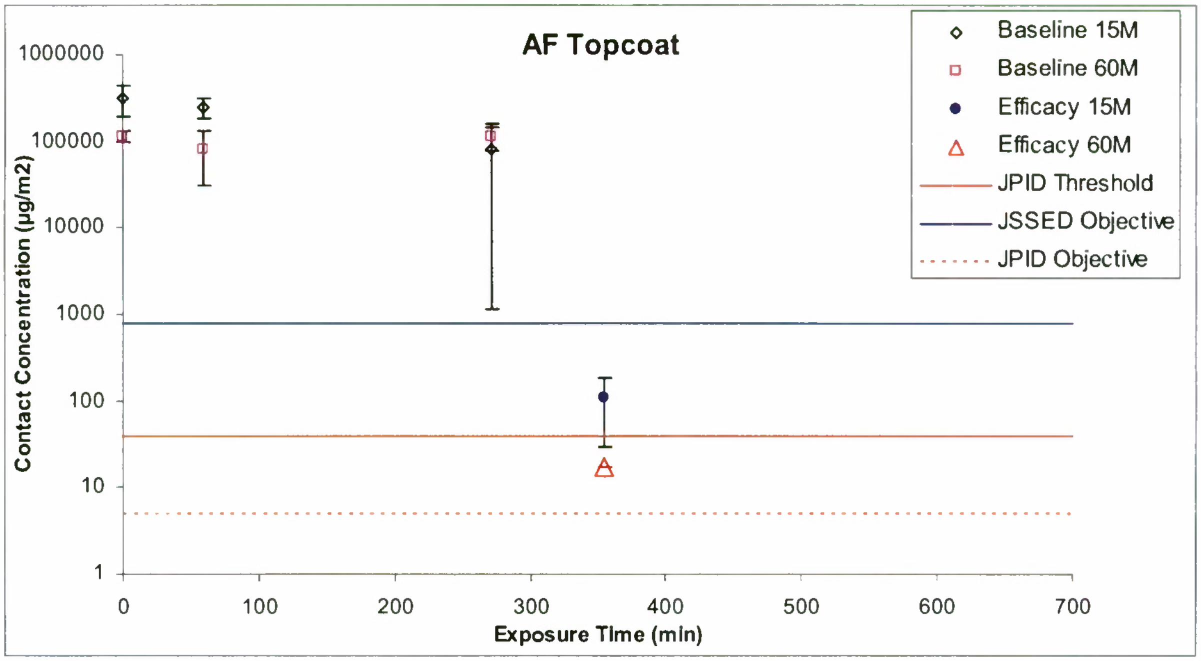


Figure 60. VX contact concentration vs. time for AF topcoat.

Table 85. VX 1 g/m² starting challenge contact test results for aluminum.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Aluminum	35	Ext. Eff.	15M	0	4/4	487690 ± 23757¤	487.690 ± 23.757¤
Aluminum	15	Baseline	15M	59	2/3	591990 ± 7361	591.990 ± 7.361
Aluminum	15	Baseline	15M	272	3/3	694790 ± 251796	694.790 ± 251.796
Aluminum	16	Efficacy	15M	241	4/5	0 ± 0	0.000 ± 0.000
Aluminum	14	Scoping	15M	237	4/4	64 ± 51	0.064 ± 0.051
Aluminum	35	Ext. Eff.	60M	0	4/4	8049 ± 5405	8.049 ± 5.405
Aluminum	15	Baseline	60M	59	2/3	25117 ± 5432	25.117 ± 5.432
Aluminum	15	Baseline	60M	272	3/3	217410 ± 165858	217.410 ± 165.858
Aluminum	16	Efficacy	60M	241	4/5	19 ± 4	0.019 ± 0.004
Aluminum	14	Scoping	60M	237	3/4	6 ± 5	0.006 ± 0.005

¤ - Sample concentration is less than lowest standard; data is suspect.

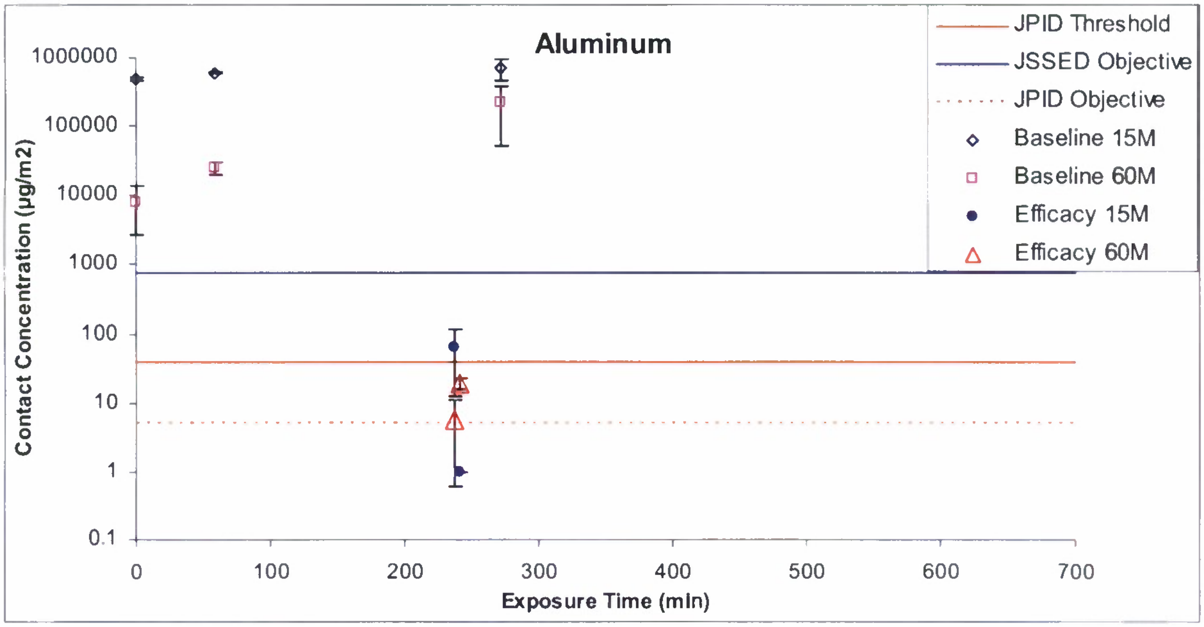


Figure 61. VX contact concentration vs. time for aluminum.

Table 86. VX 1 g/m² starting challenge contact test results for CARC.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
CARC	35	Ext. Eff.	15M	0	4/4	1152588 ± 90945	1152.588 ± 90.945
CARC	15	Baseline	15M	59	3/3	837838 ± 26741	837.838 ± 26.741
CARC	15	Baseline	15M	272	3/3	540886 ± 191031	540.886 ± 191.031
CARC	14	Scoping	15M	237	3/4	17 ± 11	0.017 ± 0.011
CARC	17	Efficacy	15M	354	4/5	41 ± 19	0.041 ± 0.019
CARC	35	Ext. Eff.	60M	0	4/4	166603 ± 41856	166.603 ± 41.856
CARC	15	Baseline	60M	59	2/3	53788 ± 3473	53.788 ± 3.473
CARC	15	Baseline	60M	272	3/3	37024 ± 4734	37.024 ± 4.734
CARC	14	Scoping	60M	237	4/4	71 ± 73	0.071 ± 0.073
CARC	17	Efficacy	60M	354	4/5	27 ± 16‡	0.027 ± 0.016‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

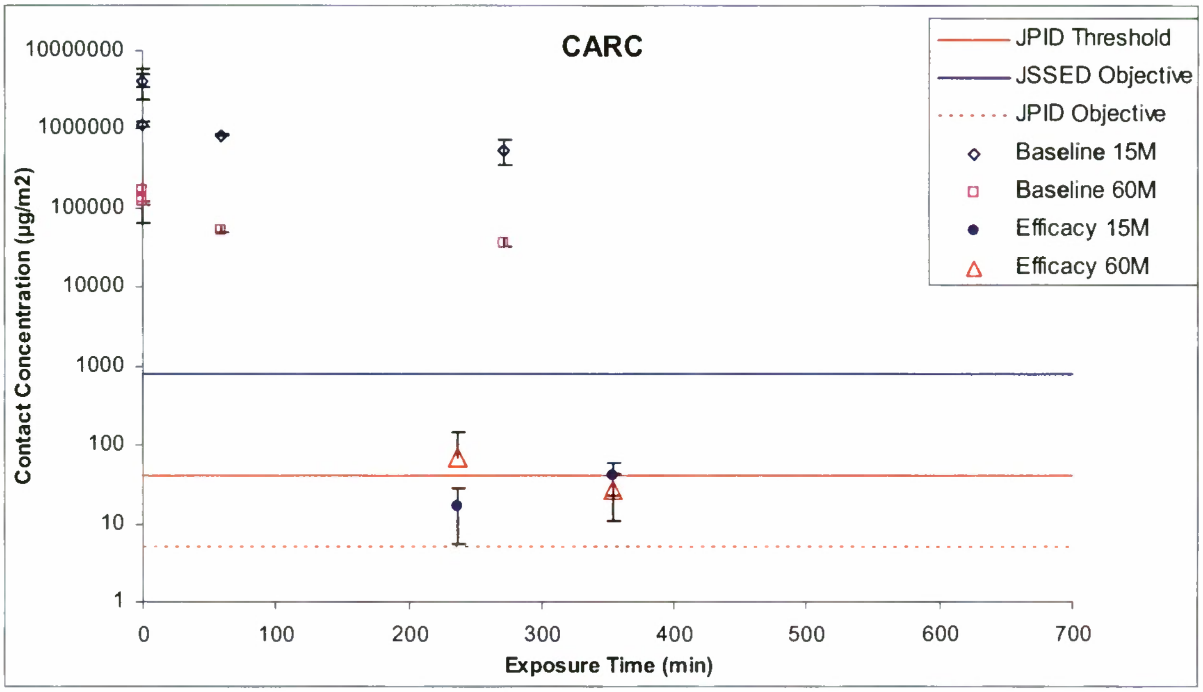


Figure 62. VX contact concentration vs. time for CARC.

Table 87. VX 1 g/m² starting challenge contact test results for glass.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Glass	35	Ext. Eff.	15M	0	4/4	240109 ± 193646	240.109 ± 193.646
Glass	15	Baseline	15M	59	3/3	887080 ± 371860	887.080 ± 371.860
Glass	15	Baseline	15M	272	3/3	993461 ± 92627	993.461 ± 92.627
Glass	16	Efficacy	15M	241	4/5	7034 ± 3958	7.034 ± 3.958
Glass	35	Ext. Eff.	60M	0	4/4	8837 ± 10399	8.837 ± 10.399
Glass	15	Baseline	60M	59	2/3	9928 ± 14041	9.928 ± 14.041
Glass	15	Baseline	60M	272	2/3	0 ± 0	0.000 ± 0.000
Glass	16	Efficacy	60M	241	5/5	2188 ± 1527	2.188 ± 1.527

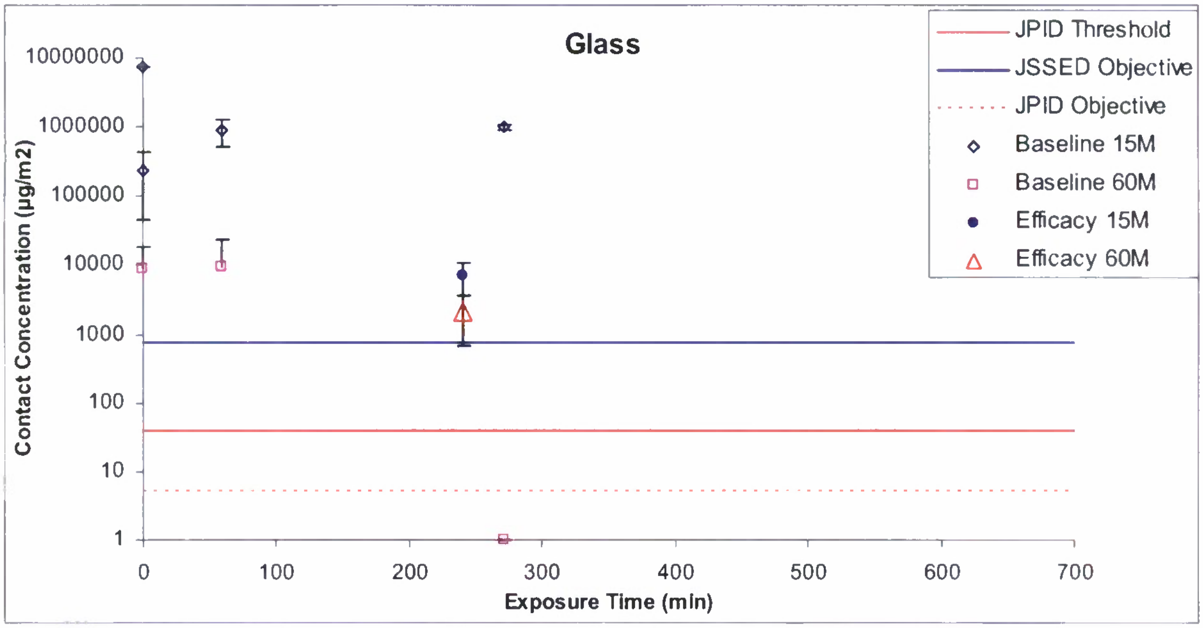


Figure 63. VX contact concentration vs. time for glass.

Table 88. VX 1 g/m² starting challenge contact test results for Kapton.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Kapton	35	Ext. Eff.	15M	0	4/4	961330 ± 84113	961.330 ± 84.113
Kapton	15	Baseline	15M	59	3/3	351409 ± 112571	351.409 ± 112.571
Kapton	15	Baseline	15M	272	3/3	325229 ± 57902	325.229 ± 57.902
Kapton	16	Efficacy	15M	241	4/5	30 ± 4	0.030 ± 0.004
Kapton	35	Ext. Eff.	60M	0	4/4	5133 ± 3228	5.133 ± 3.228
Kapton	15	Baseline	60M	59	3/3	158980 ± 160937	158.980 ± 160.937
Kapton	15	Baseline	60M	272	3/3	195204 ± 25185	195.204 ± 25.185
Kapton	16	Efficacy	60M	241	5/5	12 ± 17	0.012 ± 0.017

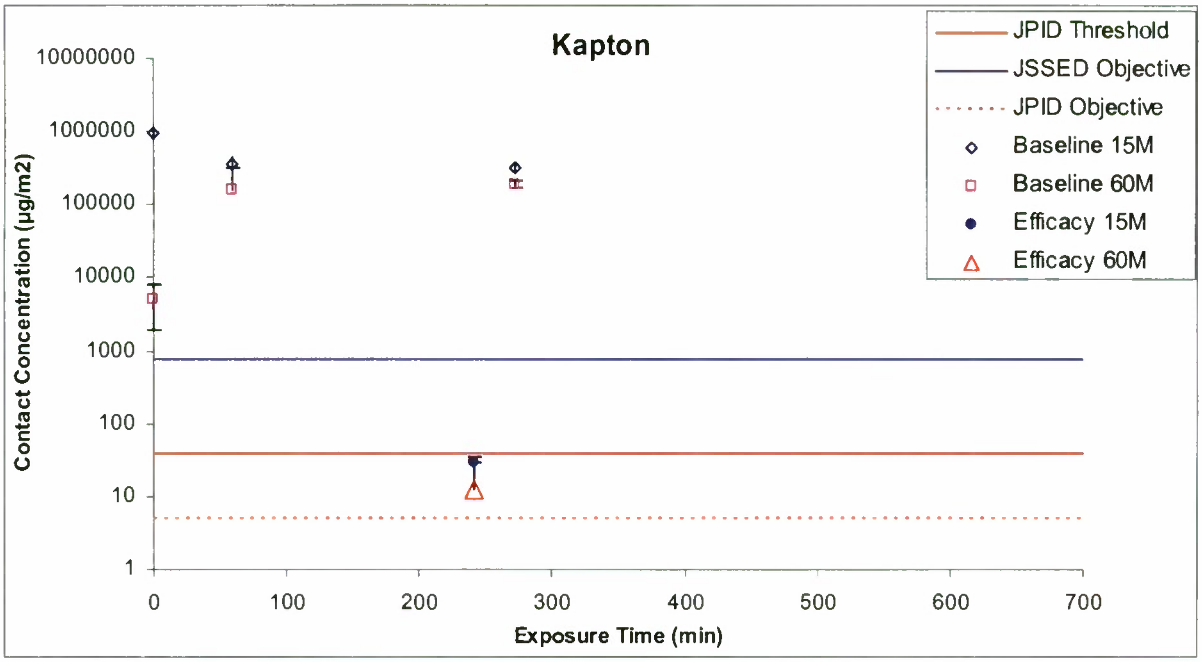


Figure 64. VX contact concentration vs. time for Kapton.

Table 89. VX 1 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Polycarb.	35	Ext. Eff.	15M	0	3/4	988403 ± 48288¤	988.403 ± 48.288¤
Polycarb.	15	Baseline	15M	59	3/3	996397 ± 13857	996.397 ± 13.857
Polycarb.	15	Baseline	15M	272	2/3	1058119 ± 24745	1058.119 ± 24.745
Polycarb.	16	Efficacy	15M	241	4/5	116 ± 232‡	0.116 ± 0.232‡
Polycarb.	14	Scoping	15M	237	4/4	15330 ± 6358	15.330 ± 6.358
Polycarb.	35	Ext. Eff.	60M	0	4/4	335 ± 245¤	0.335 ± 0.245¤
Polycarb.	15	Baseline	60M	59	2/3	0 ± 0	0.000 ± 0.000
Polycarb.	15	Baseline	60M	272	3/3	3405 ± 1220	3.405 ± 1.220
Polycarb.	16	Efficacy	60M	241	4/5	28 ± 28	0.028 ± 0.028
Polycarb.	14	Scoping	60M	237	4/4	10728 ± 8688	10.728 ± 8.688

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.
¤ - Sample concentration is less than lowest standard, data is suspect.

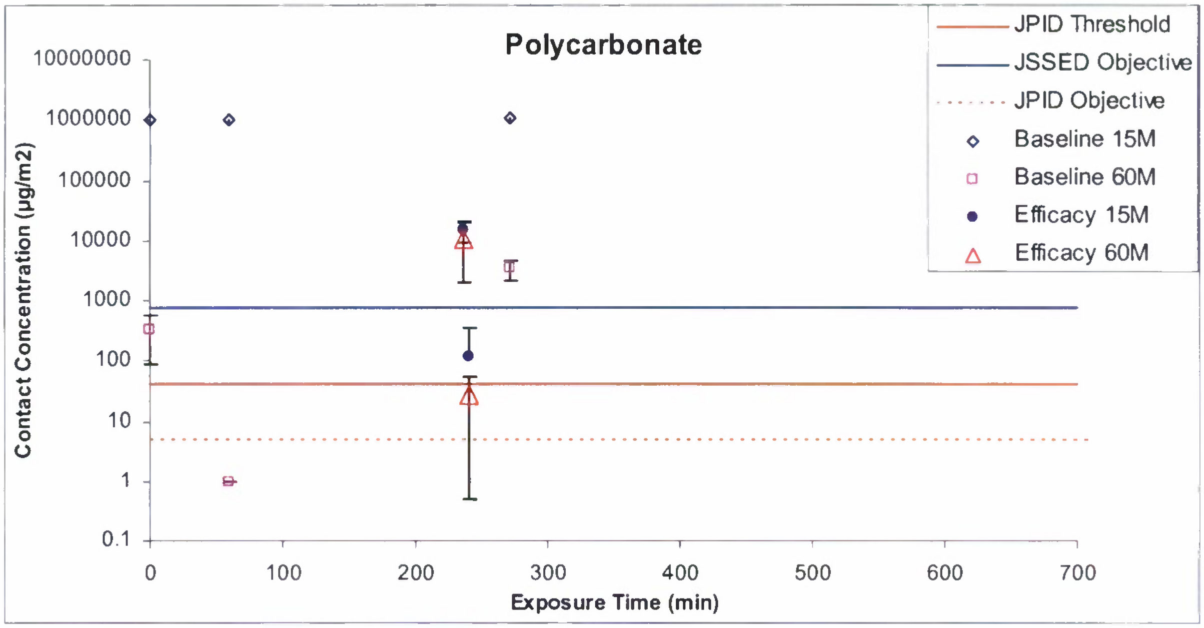


Figure 65. VX contact concentration vs. time for polycarbonate.

Table 90. VX 1 g/m² starting challenge contact test results for silicone.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Silicone	35	Ext. Eff.	15M	0	4/4	98424 ± 11234	98.424 ± 11.234
Silicone	15	Baseline	15M	272	2/3	5825 ± 9	5.825 ± 0.009
Silicone	15	Baseline	15M	478	2/3	6450 ± 241	6.450 ± 0.241
Silicone	14	Scoping	15M	237	4/4	31310 ± 10431	31.310 ± 10.431
Silicone	17	Efficacy	15M	354	5/5	16421 ± 6096	16.421 ± 6.096
Silicone	35	Ext. Eff.	60M	0	4/4	181700 ± 27094	181.700 ± 27.094
Silicone	15	Baseline	60M	272	3/3	6207 ± 1656	6.207 ± 1.656
Silicone	15	Baseline	60M	478	3/3	2434 ± 2135	2.434 ± 2.135
Silicone	14	Scoping	60M	237	4/4	15298 ± 10737	15.298 ± 10.737
Silicone	17	Efficacy	60M	354	5/5	7370 ± 4037	7.370 ± 4.037

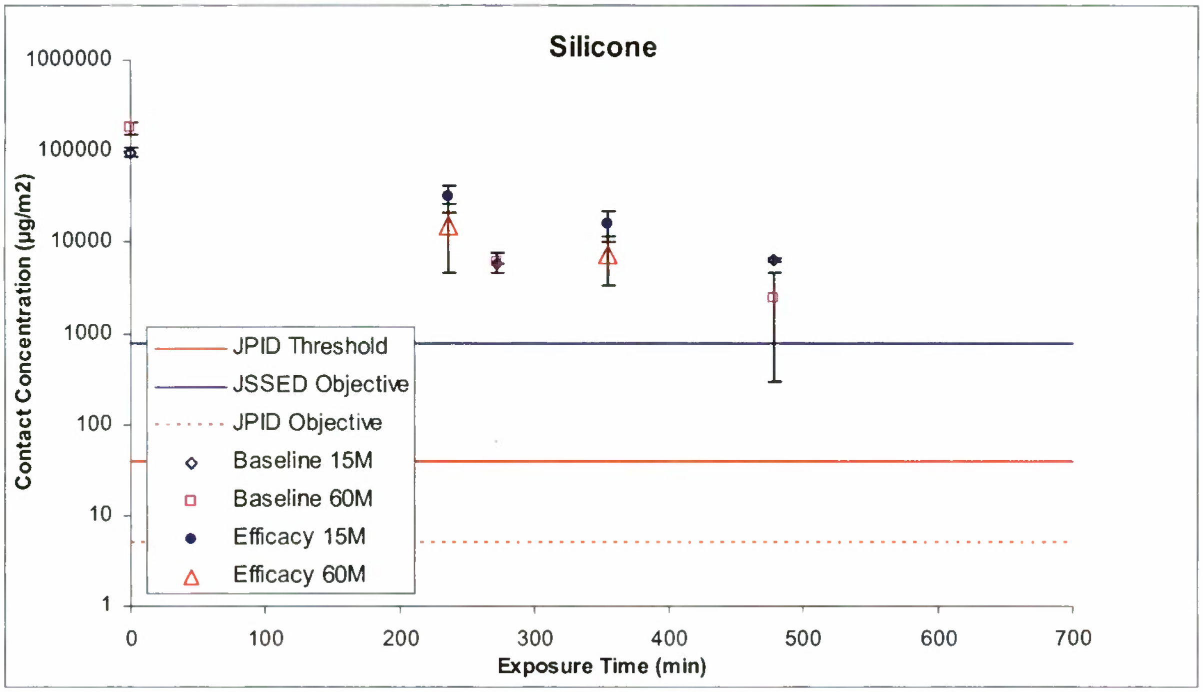


Figure 66. VX contact concentration vs. time for silicone.

Table 91. VX 1 g/m² starting challenge contact test results for Viton.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Viton	35	Ext. Eff.	15M	0	3/4	34356 ± 8373	34.356 ± 8.373
Viton	15	Baseline	15M	272	3/3	74747 ± 76176	74.747 ± 76.176
Viton	15	Baseline	15M	478	3/3	28868 ± 28855	28.868 ± 28.855
Viton	17	Efficacy	15M	354	5/5	28646 ± 20873	28.646 ± 20.873
Viton	35	Ext. Eff.	60M	0	4/4	89307 ± 9753	89.307 ± 9.753
Viton	15	Baseline	60M	272	3/3	32795 ± 28053	32.795 ± 28.053
Viton	15	Baseline	60M	478	2/3	14391 ± 706	14.391 ± 0.706
Viton	17	Efficacy	60M	354	5/5	14375 ± 11108	14.375 ± 11.108

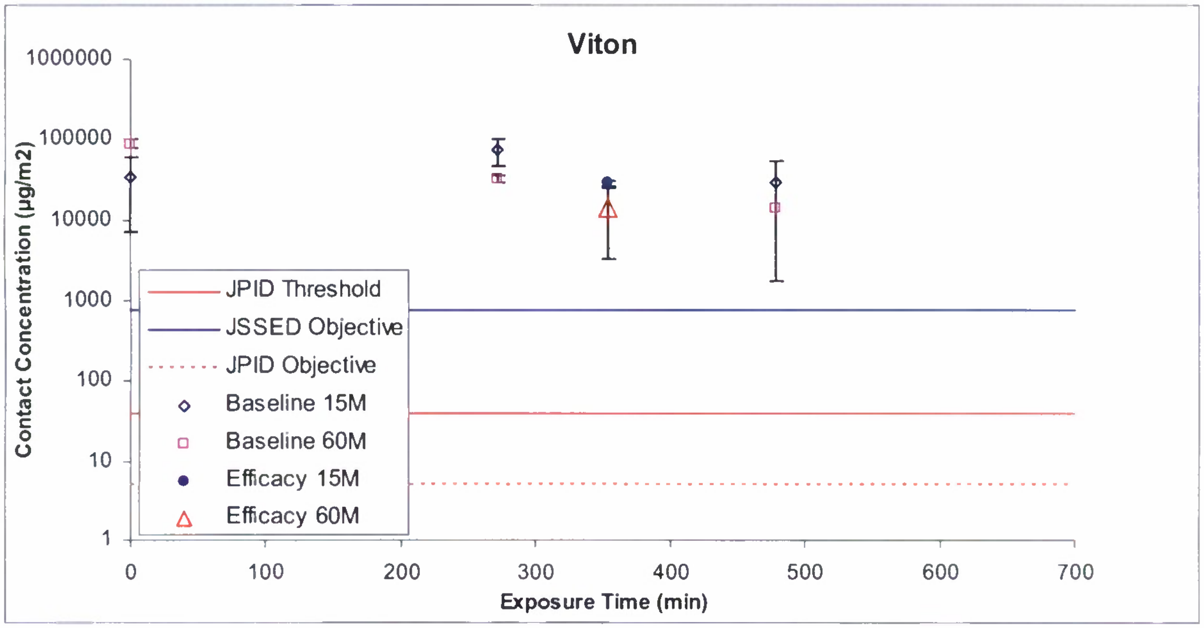


Figure 67. VX contact concentration vs. time for Viton.

In addition to the 15M and 60M test specified in the TOP, a residual extraction analysis was performed on each contact sample (Table 92). The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, these values under estimated the actual residual agent that was present. The acquisition of these results was not specified in the TOP or the ORDs and, therefore, the results have no comparison to ORD values.

A full investigation of the 10 g/m^2 starting challenge was not performed for VX; however, a limited set of tests was performed on a select set of materials (Table 95 – Table 97). Table 93 shows that the wipe technology does not reduce the VX concentration to less than 1 g/m^2 starting challenge. Thus, the comparison of JSSED to the 1 g/m^2 starting challenge data was not valid. Table 95 – Table 97 show that use of mVHP alone did not decontaminate any material to the JSSED ORD. See Section 11.5 for results of a VX 10 g/m^2 starting challenge contact test on a DVD player.

Table 92. VX 1 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Run Type	Test Set	Exp Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
AF topcoat	35	Ext. Eff.	RES	0	4/4	363947 ± 7163	363.947 ± 7.163
AF topcoat	15	Baseline	RES	59	3/3	762080 ± 142718	762.080 ± 142.718
AF topcoat	15	Baseline	RES	272	3/3	772644 ± 37272	772.644 ± 37.272
Aluminum	35	Ext. Eff.	RES	0	4/4	3 ± 1	0.003 ± 0.001
Aluminum	15	Baseline	RES	59	3/3	3773 ± 1282	3.773 ± 1.282
Aluminum	15	Baseline	RES	272	3/3	39147 ± 50788	39.147 ± 50.788
Aluminum	16	Efficacy	RES	241	4/5	0 ± 0	0.000 ± 0.000
Aluminum	14	Scoping	RES	237	4/4	0 ± 0	0.000 ± 0.000
CARC	35	Ext. Eff.	RES	0	4/4	363989 ± 47552	363.989 ± 47.552
CARC	15	Baseline	RES	59	3/3	73844 ± 25718	73.844 ± 25.718
CARC	15	Baseline	RES	272	3/3	212974 ± 54412	212.974 ± 54.412
CARC	14	Scoping	RES	237	3/4	0 ± 0	0.000 ± 0.000
CARC	17	Efficacy	RES	354	5/5	20 ± 15‡	0.020 ± 0.015‡
Glass	35	Ext. Eff.	RES	0	4/4	9 ± 8	0.009 ± 0.008
Glass	15	Baseline	RES	59	2/3	0 ± 0	0.000 ± 0.000
Glass	15	Baseline	RES	272	2/3	0 ± 0	0.000 ± 0.000
Glass	16	Efficacy	RES	241	4/5	705 ± 385	0.705 ± 0.385
Kapton	35	Ext. Eff.	RES	0	4/4	67 ± 35	0.067 ± 0.035
Kapton	15	Baseline	RES	59	3/3	444230 ± 28068	444.230 ± 28.068
Kapton	15	Baseline	RES	272	3/3	499569 ± 30807	499.569 ± 30.807
Kapton	16	Efficacy	RES	241	4/5	7 ± 14	0.007 ± 0.014
Polycarb.	35	Ext. Eff.	RES	0	4/4	131 ± 65¤	0.131 ± 0.065¤
Polycarb.	15	Baseline	RES	59	2/3	0 ± 0	0.000 ± 0.000
Polycarb.	15	Baseline	RES	272	3/3	3169 ± 481	3.169 ± 0.481
Polycarb.	16	Efficacy	RES	241	5/5	228 ± 159	0.228 ± 0.159
Polycarb.	14	Scoping	RES	237	3/4	1 ± 0	0.001 ± 0.000
Silicone	35	Ext. Eff.	RES	0	4/4	1740553 ± 129214	1740.553 ± 129.214
Silicone	15	Baseline	RES	272	3/3	292393 ± 64156	292.393 ± 64.156
Silicone	15	Baseline	RES	478	3/3	240448 ± 39873	240.448 ± 39.873
Silicone	14	Scoping	RES	237	4/4	17 ± 3	0.017 ± 0.003
Viton	35	Ext. Eff.	RES	0	4/4	1017442 ± 49022	1017.442 ± 49.022
Viton	15	Baseline	RES	272	2/3	1191844 ± 10760	1191.844 ± 10.760
Viton	15	Baseline	RES	478	3/3	813044 ± 162416	813.044 ± 162.416

¤ - Sample concentration is less than lowest standard; data is suspect.

Table 93. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results.

Material	Wipe	Exp. Time (min)	Test Set	Reps	VX Contact Concentration (μg/m²)	VX Contact Concentration (mg/m²)
Aluminum	Yes	0	15M	4/4	7070104 ± 969106	7070.104 ± 969.106
Aluminum	Yes	0	60M	4/4	19869 ± 8389	19.869 ± 8.389
CARC	Yes	0	15M	4/4	4137790 ± 1792522	4137.790 ± 1792.522
CARC	Yes	0	60M	3/4	133846 ± 23143	133.846 ± 23.143
Glass	Yes	0	15M	4/4	5077158 ± 1857768‡	5077.158 ± 1857.768‡
Glass	Yes	0	60M	2/4	15468 ± 9852‡	15.468 ± 9.852‡
Silicone	Yes	0	15M	4/4	2667982 ± 328310	2667.982 ± 328.310
Silicone	Yes	0	60M	4/4	448843 ± 47034	448.843 ± 47.034

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

Table 94. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results.

Material	Wipe	Exp. Time (min)	Test Set	Reps	VX Contact Concentration (μg/m²)	VX Contact Concentration (mg/m²)
Aluminum	Yes	0	RES	3/4	6 ± 4	0.006 ± 0.004
CARC	Yes	0	RES	3/4	290673 ± 136574	290.673 ± 136.574
Glass	Yes	0	RES	3/4	26 ± 8	0.026 ± 0.008
Silicone	Yes	0	RES	3/4	4152475 ± 178224	4152.475 ± 178.224

Table 95. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results.

Material	Wipe	Exp. Time (min)	Test Set	Reps	VX Contact Concentration (μg/m²)	VX Contact Concentration (mg/m²)
Aluminum	No	0	15M	4/4	7469364 ± 29213	7469.364 ± 29.213
			60M	4/4	109373 ± 83679	109.373 ± 83.679
CARC	No	0	15M	4/4	4153577 ± 778964	4153.577 ± 778.964
			60M	4/4	124026 ± 60497	124.026 ± 60.497
Glass	No	0	15M	3/4	7258938 ± 69072	7258.938 ± 69.072
			60M	4/4	84312 ± 100533	84.312 ± 100.533
Silicone	No	0	15M	4/4	2051061 ± 839472	2051.061 ± 839.472
			60M	3/4	418615 ± 7598	418.615 ± 7.598

Table 96. VX 10 g/m² starting challenge extraction efficiency test (run 35), contact test residual agent results.

Material	Wipe	Exp. Time (min)	Test Set	Reps	VX Contact Concentration (μg/m²)	VX Contact Concentration (mg/m²)
Aluminum	No	0	RES	4/4	13074 ± 7426	13.074 ± 7.426
CARC	No	0	RES	3/4	2785003 ± 67855	2785.003 ± 67.855
Glass	No	0	RES	4/4	289739 ± 210682	289.739 ± 210.682
Silicone	No	0	RES	4/4	3502467 ± 477045	3502.467 ± 477.045

Table 97. VX 10 g/m² starting challenge efficacy test (run 30).

Material	Wipe	Test Set	Exp. Time (min)	Reps	VX Contact Concentration (µg/m²)	VX Contact Concentration (mg/m²)
Glass	No	15M	600	4/5	397920 ± 57628§‡	397.920 ± 57.628§‡
Glass	No	60M	600	5/5	259803 ± 131633§‡	259.803 ± 131.633§‡
Glass	Yes	15M	600	4/5	151 ± 20‡	0.151 ± 0.020‡
Glass	Yes	60M	600	4/5	120 ± 50‡	0.120 ± 0.050‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.
§ - data represents a concentration greater than the calibration range; data is suspect.
NOTE:
Yellow = Combination of mVHP and pre-wipe technology
White = Exclusively mVHP technology

9.5 Contact Test Results Compared to ORDs for VX 1 g/m² Starting Challenge

The specified VX ORD values for JPID and JSSED are provided in Table 98. The post-decontamination vapor test data for the approximately 1 g/m² VX starting challenge was directly compared to the ORD vapor hazard values and presented in Table 99. The results are summarized in the following list.

- **AF Topcoat** was a factor of 21.53 times higher than the JPID objective ORD after 354 min of decontamination.
- **Aluminum** was a factor of 3.9 times higher than the JPID objective ORD after 341 min of decontamination.
- **CARC** was a factor of 8.3 times higher than the JPID objective ORD after 354 min of decontamination.
- **Glass** was a factor of 437 times higher than the JPID objective ORD after 241 min of decontamination.
- **Kapton** was a factor of 6.0 times higher than the JPID objective ORD after 241 min of decontamination.
- **Polycarbonate** was a factor of 23 times higher than the JPID objective ORD after 241 min of decontamination.
- **Silicone** was a factor of 3284 times higher than the JPID objective ORD after 354 min of decontamination.
- **Viton** was a factor of 5729 times higher than the JPID objective ORD after 354 min of decontamination.

Table 100 shows that the pre-wipe method did not decontaminate any material to the JSSED threshold ORD. It also shows that the remaining agent was greater than 1 g/m². This indicated that the 1 g/m² starting challenge data could not be used to evaluate the JSSED ORD. However, since the pre-wipe method was not optimized for VX, there was room for optimization of the technique with this agent.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). Comparions are made to the JSSED ORD values under the assumption that a prewipe could remove 90% of the initial contamination, reducing the threat from 10 g/m² to 1 g/m². The comparisons were made to the JSSED requirements for estimation purposes only. If this assumption is valid, this 1 g/m² data may be sufficient to evaluate the mVHP technology against both starting challenges, with the caveat that high contamination densities incorporate the use of a pre-wipe. This assumption has not yet been proven.

Table 98. Contact ORD values for VX.

ORD	Starting Challenge (g/m²)	VX Contact Concentration	
		(µg/m²)	(mg/m²)
JPID Threshold	1	40	0.04
JPID Objective	1	5	0.00*
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	780	0.78

* This value was set as 0.0 mg/m² in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m² (when rounded to the presented accuracy would return a result of 0.1 mg/m²) fail the JPID objective level.

Table 99. VX 1 g/m² starting challenge contact test results compared to ORD.

Material	Exp. Time (min)	Run	Run Type	Test Set	VX Contact Concentration (mg/m²)	JPID Thresh. Factor	JSSED Obj. Factor	JPID Obj. Factor
AF topcoat	354	17	Efficacy	15M	0.108 ± 0.079	2.69	0.14	21.53
				60M	0.017 ± 0.000	0.43	0.02	3.46
Aluminum	237	14	Scoping	15M	0.064 ± 0.051	1.60	0.08	12.83
				60M	0.006 ± 0.005	0.14	0.01	1.15
	241	16	Efficacy	15M	0.000 ± 0.000	0.00	0.00	0.00
				60M	0.019 ± 0.004	0.48	0.02	3.87
CARC	237	14	Scoping	15M	0.017 ± 0.011	0.42	0.02	3.32
				60M	0.071 ± 0.073	1.77	0.09	14.16
	354	17	Efficacy	15M	0.041 ± 0.019	1.03	0.05	8.28
				60M	0.027 ± 0.016‡	0.67‡	0.03‡	5.36‡
Glass	241	16	Efficacy	15M	7.034 ± 3.958	175.84	9.02	1406.73
				60M	2.188 ± 1.527	54.69	2.80	437.51
Kapton	241	16	Efficacy	15M	0.030 ± 0.004	0.75	0.04	6.03
				60M	0.012 ± 0.017	0.31	0.02	2.47
Polycarb.	237	14	Scoping	15M	15.330 ± 6.358	383.26	19.65	3066.06
				60M	10.728 ± 8.688	268.20	13.75	2145.58
	241	16	Efficacy	15M	0.116 ± 0.232‡	2.90‡	0.15‡	23.21‡
				60M	0.028 ± 0.028	0.71	0.04	5.65
Silicone	237	14	Scoping	15M	31.310 ± 10.431	782.75	40.14	6261.99
				60M	15.298 ± 10.737	382.45	19.61	3059.62
	354	17	Efficacy	15M	16.421 ± 6.096	410.52	21.05	3284.15
				60M	7.370 ± 4.037	184.25	9.45	1474.03
Viton	354	17	Efficacy	15M	28.646 ± 20.873	716.14	36.73	5729.12
				60M	14.375 ± 11.108	359.37	18.43	2874.93

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

Table 100. VX 10 g/m² starting challenge comparison to JSSED ORD for pre-wipe method only.

Material	Wipe	Exp. Time (min)	Test Set	VX Contact Concentration (mg/m²)	JSSED Thresh. Factor
Aluminum	Yes	0	15M 60M	7070.104 ± 969.106 19.869 ± 8.389	9064.24 25.47
CARC	Yes	0	15M 60M	4137.790 ± 1792.522 133.846 ± 23.143	5304.86 171.60
Glass	Yes	0	15M 60M	5077.158 ± 1857.768 15.468 ± 9.852	6509.18 19.83
Silicone	Yes	0	15M 60M	2667.982 ± 328.310 448.843 ± 47.034	3420.49 575.44

10. TEST RESULTS AND DISCUSSION: GD 1 g/m^2 TEST

10.1 Test Summary for GD 1 g/m² Starting Challenge

The mVHP testing starting challenge was approximately 1 g/m² applied as four 0.5 µL drops of GD from a repeater syringe. The error bars presented in the tables and figures represent one standard deviation of the data. For each of the figures the ORD values are drawn as solid lines, these values are reviewed in Table 5. Any data point above a solid line indicates that it did not meet the ORD value.

The conditions for each experimental run and exposure time are listed in Table 11 and Table 12. The hydrogen peroxide and ammonia fumigant concentrations, and the temperature and relative humidity control charts are provided in Appendix B.

GD was the first agent analyzed in this test. The sample blanks exhibited some evidence of cross contamination. This cross contamination was related to sample transport after decontamination and before analysis. The remedy to this problem was to cover the individual samples during transport between tests. This discussion is described in more detail in Section 11.12.

10.2 Vapor Test Results for GD 1 g/m² Starting Challenge

The results of the vapor test for 1 g/m² GD starting challenge are presented in Table 101–Table 104 and illustrated in Figure 68 – Figure 71. Four replicate coupons were measured for scoping runs, and five replicates were measured for efficacy runs, using each material with at least two exposure times each. These results are numerically compared to the ORDs in Section 10.3.

There are a limited number of analytical tests that can be performed in a run. For this data set, aluminum and Kapton vapor tests were performed for only one exposure time to enable the acquisition of silicone and Viton vapor samples at extended time points.

Table 101. GD 1 g/m² starting challenge vapor results for glass and polycarbonate.

Material	Run	Run Type	Exp. Time (min)	Reps	GD Vapor Concentration (μg/m³)	GD Vapor Concentration (mg/m³)
Glass	5	Efficacy	124	4/5	0.3 ± 0.0	0.0003 ± 0.0000
Glass	3	Scoping	180	3/4	1.0 ± 1.0	0.0010 ± 0.0010
Polycarb.	5	Efficacy	124	4/5	0.4 ± 0.1	0.0004 ± 0.0001
Polycarb.	3	Scoping	180	3/4	0.6 ± 0.1	0.0006 ± 0.0001

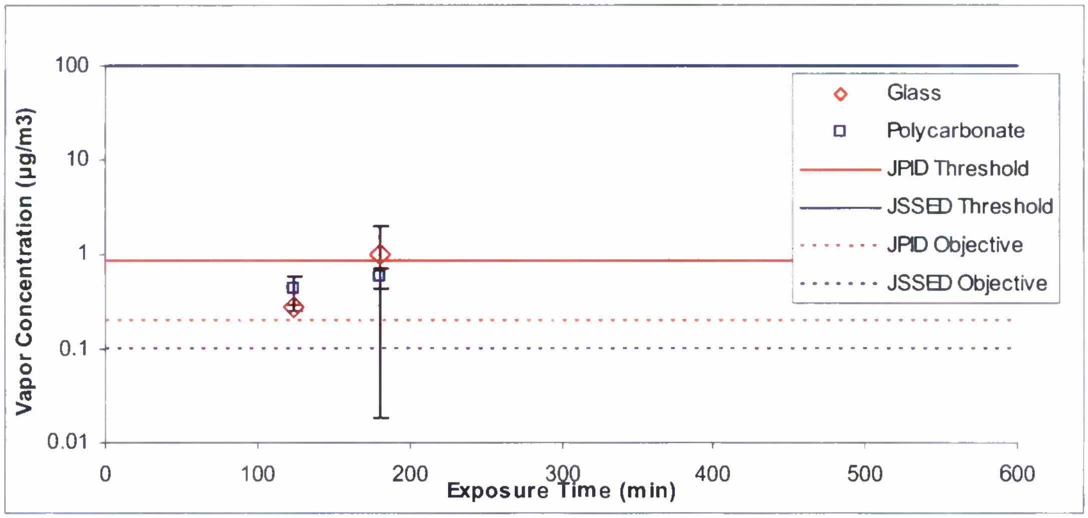


Figure 68. GD vapor concentration vs. time for glass and polycarbonate.

Table 102. GD 1 g/m² starting challenge vapor results for AF topcoat and CARC.

Material	Run	Run Type	Exp. Time (min)	Reps	GD Vapor Concentration (μg/m³)	GD Vapor Concentration (mg/m³)
AF topcoat	6	Efficacy	239	4/5	5.4 ± 0.4	0.0054 ± 0.0004
AF topcoat	6	Efficacy	482	4/5	5.9 ± 0.1	0.0059 ± 0.0001
CARC	3	Scoping	62	3/4	6.6 ± 1.2	0.0066 ± 0.0012
CARC	3	Scoping	180	3/4	1.8 ± 1.1	0.0018 ± 0.0011
CARC	6	Efficacy	239	5/5	2.3 ± 1.3	0.0023 ± 0.0013
CARC	6	Efficacy	482	3/5	2.5 ± 2.0	0.0025 ± 0.0020

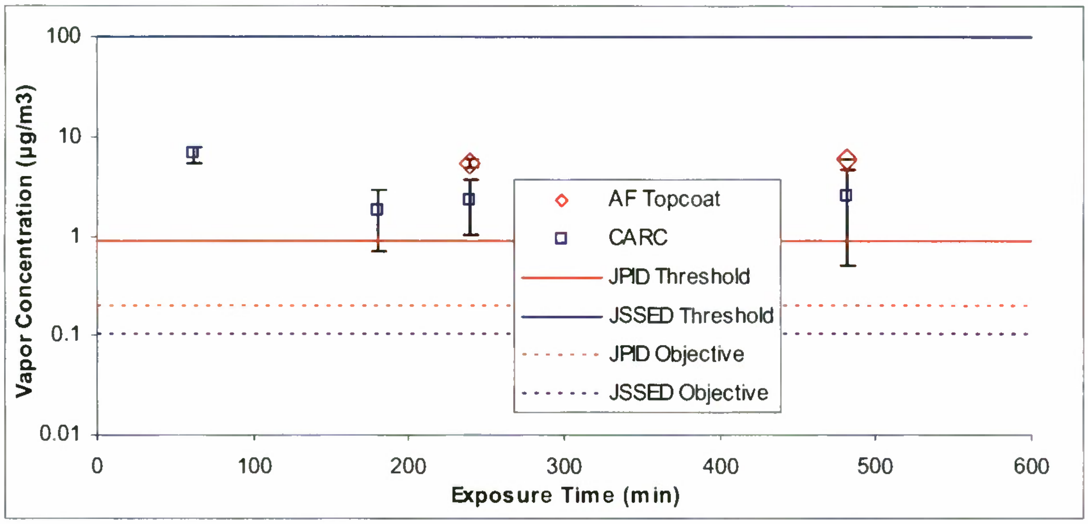


Figure 69. GD vapor concentration vs. time for AF topcoat and CARC.

Table 103. GD 1 g/m² starting challenge vapor results for silicone and Viton.

Material	Run	Run Type	Exp. Time (min)	Reps	GD Vapor Concentration (µg/m³)	GD Vapor Concentration (mg/m³)
Silicone	6	Efficacy	239	5/5	3.8 ± 0.4	0.0038 ± 0.0004
Silicone	6	Efficacy	482	4/5	3.7 ± 0.1	0.0037 ± 0.0001
Viton	6	Efficacy	239	5/5	2.7 ± 1.7	0.0027 ± 0.0017
Viton	6	Efficacy	482	3/5	5.7 ± 2.7	0.0057 ± 0.0027

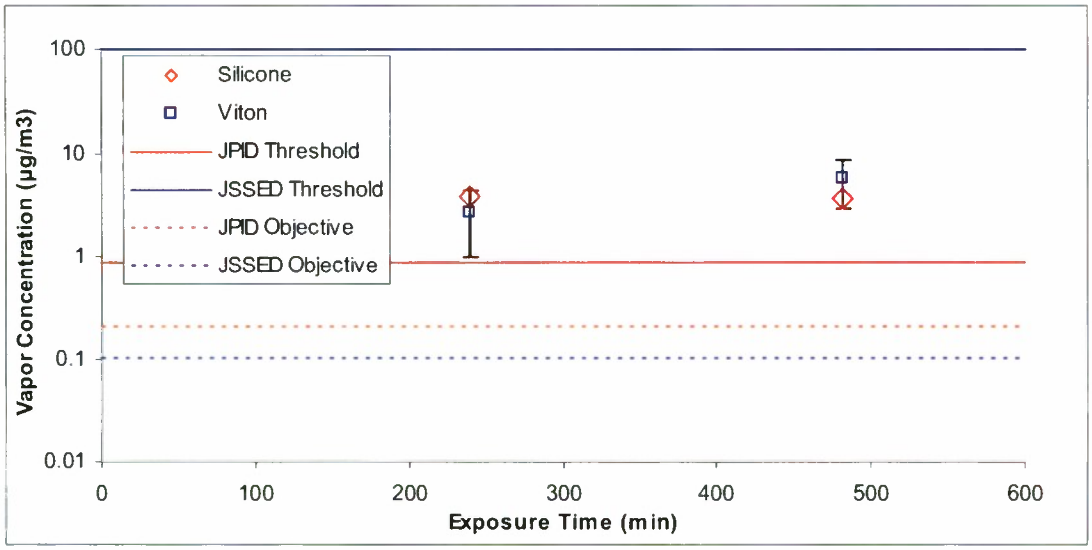


Figure 70. GD vapor concentration vs. time for silicone and Viton.

Table 104. GD 1 g/m² starting challenge vapor results for aluminum and Kapton.

Material	Run	Run Type	Exp. Time (min)	Reps	GD Vapor Concentration (μg/m³)	GD Vapor Concentration (mg/m³)
Aluminum	5	Efficacy	124	5/5	0.4 ± 0.2	0.0004 ± 0.0002
Kapton	5	Efficacy	124	5/5	1.1 ± 1.2	0.0011 ± 0.0012

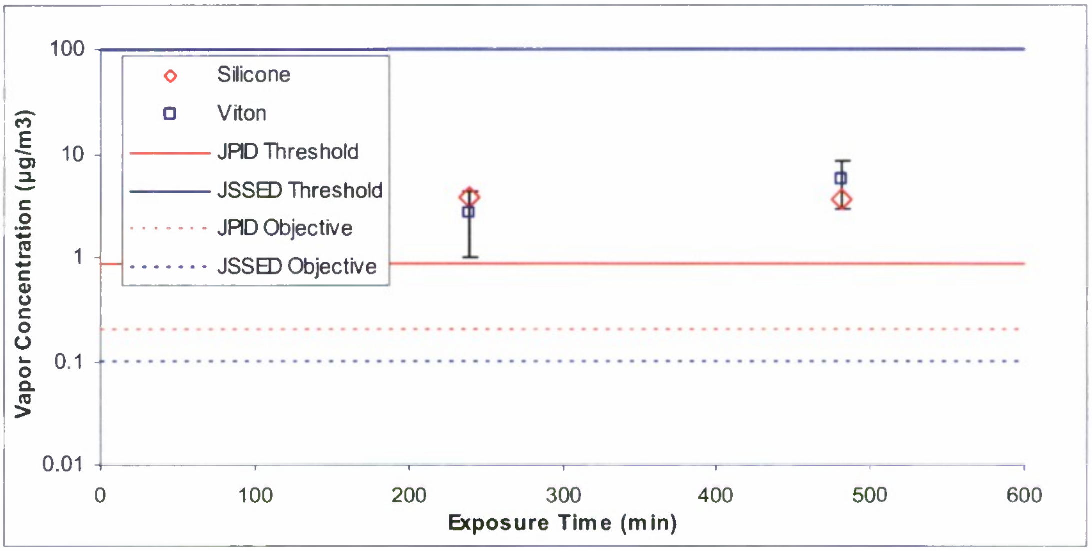


Figure 71. GD vapor concentration vs. time for aluminum and Kapton.

10.3 Vapor Test Results Compared to ORDs for GD 1 g/m² Starting Challenge

The specified GD ORD values for JPID and JSSED are provided in Table 105. The post-decontamination vapor test data for the approximately 1 g/m² GD starting challenge test was directly compared to the ORD vapor hazard values and presented in Table 106.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The Table 106 results for a 1 g/m² GD starting challenge are summarized in the following list.

- **AF Topcoat** was a factor of 29 times the JPID objective ORD after 482 min of decontamination.
- **Aluminum** was a factor of 1.9 times the JPID objective ORD after 124 min of decontamination.
- **CARC** was a factor of 12.7 times the JPID objective ORD after 482 min of decontamination.
- **Glass** was a factor of 5.0 times the JPID objective ORD after 180 min of decontamination.
- **Kapton** was a factor of 5.4 times the JPID objective ORD after 124 min of decontamination.
- **Polycarbonate** was a factor of 2.9 times the JPID objective ORD after 180 min of decontamination.

- **Silicone** was a factor of 19 times the JPID objective ORD after 482 min of decontamination.
- **Viton** was a factor of 28 times the JPID objective ORD after 482 min of decontamination.

The JSSED ORD values specify a 10 g/m² starting challenge. The data presented here corresponds to a 1 g/m² starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m² to 1 g/m² for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m² data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m² data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 105. Vapor ORD values for GD.

ORD	Starting Challenge (g/m²)	GD Vapor Concentration	
		(μg/m³)	(mg/m³)
JPID Threshold	1	0.87	0.00087
JPID Objective	1	0.2	0.0002
JSSED Threshold	10	100	0.1
JSSED Objective	10	0.1	0.0001

Table 106. Vapor efficacy of mVHP on GD: 1 g/m² starting challenge.

Material	Exp. Time (min)	GD Vapor Concentration (mg/m³)	JPID Thresh. Factor	JSSED Thresh. Factor	JPID Obj. Factor	JSSED Obj. Factor
AF topcoat	239	0.0054 ± 0.0004	6.15	0.05	26.77	53.53
	482	0.0059 ± 0.0001	6.73	0.06	29.29	58.59
Aluminum	124	0.0004 ± 0.0002	0.44	0.00	1.91	3.82
CARC	62	0.0066 ± 0.0012	7.61	0.07	33.10	66.21
	180	0.0018 ± 0.0011	2.04	0.02	8.86	17.73
	239	0.0023 ± 0.0013	2.66	0.02	11.58	23.16
	482	0.0025 ± 0.0020	2.93	0.03	12.73	25.46
Glass	124	0.0003 ± 0.0000	0.32	0.00	1.37	2.75
	180	0.0010 ± 0.0010	1.16	0.01	5.04	10.08
Kapton	124	0.0011 ± 0.0012	1.24	0.01	5.40	10.79
Polycarb.	124	0.0004 ± 0.0001	0.51	0.00	2.20	4.40
	180	0.0006 ± 0.0001	0.66	0.01	2.87	5.73
Silicone	239	0.0038 ± 0.0004	4.37	0.04	18.99	37.98
	482	0.0037 ± 0.0001	4.28	0.04	18.63	37.26
Viton	239	0.0027 ± 0.0017	3.09	0.03	13.45	26.91
	482	0.0057 ± 0.0027	6.53	0.06	28.40	56.81

10.4 Contact Test Results for GD 1 g/m² Starting Challenge

The results of the contact test for GD 1 g/m² starting challenge are presented in Table 107 – Table 114 and illustrated in Figure 72 – Figure 79 using semi-log plots. The contact test analysis methods are discussed in Section 2.10.1.

There were four types of runs used in the contact test analysis: baseline, extraction efficiency (ext. eff.), scoping, and efficacy (see Section 2.15). The baseline and extraction efficiency runs used no decontaminant. The baseline and extraction efficiency runs are highlighted in **gray** in Table 107 – Table 114 because they do not represent decontamination efficacy data (i.e., CT $H_2O_2 = 0$). They provide a baseline for the response for natural agent weathering at ambient conditions (i.e., no mVHP treatment). For each of the graphs, the "baseline" data includes both the baseline run and the extraction efficiency run (used for exposure time zero). Extraction efficiency runs were not executed for GD because the degree of evaporation inhibited accurate measurement and lead to cross contamination. In a similar fashion, the "efficacy" data presented in the graphs includes both efficacy and scoping data (if available).

For each material at least two exposure times were measured. Some materials were used in both scoping and efficacy runs. Both sets of data are presented for these materials when available. The error bars presented on the graphs appear to be asymmetric because the y-axis of each graph is log-scaled. Some data points have only a positive error bar shown on the plot. This occurs when a data point has a standard deviation larger than the mean value, thus producing an error bar with a negative value. These negative error bars are not plotted due to the use of the semi-log scale. Another artifact of the semi-log scale is that data points with a value of zero do not appear on the graph because the log of zero is undefined. Therefore, where the data table would report a value of zero, a value of 1 µg/m² was assigned so that the data point would be plotted on the graph. There is no contact threshold for JSSED, only an objective level. These results are numerically compared to the ORDs in Section 10.5.

In addition to the 15M and 60M test specified in the TOP, a residual extraction analysis was performed on each contact sample (Table 115). The residual analysis method is described in Section 2.10.1. This data corresponds to the amount of residual agent left in the coupon that was not removed by the 15M or 60M test. This extraction process was not 100% efficient (i.e., not all of the residual agent was removed during the extraction) and was material dependent. This uncorrected data can be used as a guide to evaluate whether there was residual agent left in a coupon after the contact tests. If the extraction efficiency was less than 100% for a given material, these values under estimated the actual residual agent present. The acquisition of these results was not specified in the TOP or the ORDs and, therefore, the results have no comparison to ORD values.

Table 107. GD 1 g/m² starting challenge contact test results for AF topcoat.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
AF topcoat	26	Baseline	15M	304	4/4	24567 ± 7828	24.567 ± 7.828
AF topcoat	4	Baseline	15M	477	2/3	0 ± 0	0.000 ± 0.000
AF topcoat	26	Baseline	15M	480	4/4	10360 ± 3078	10.360 ± 3.078
AF topcoat	6	Efficacy	15M	239	4/5	1626 ± 57	1.626 ± 0.057
AF topcoat	6	Efficacy	15M	482	5/5	887 ± 809	0.887 ± 0.809
AF topcoat	26	Baseline	60M	304	3/4	24793 ± 643	24.793 ± 0.643
AF topcoat	4	Baseline	60M	477	2/3	394 ± 0	0.394 ± 0.000
AF topcoat	26	Baseline	60M	480	4/4	19061 ± 4683	19.061 ± 4.683
AF topcoat	6	Efficacy	60M	239	4/5	2414 ± 57	2.414 ± 0.057
AF topcoat	6	Efficacy	60M	482	5/5	1833 ± 227	1.833 ± 0.227

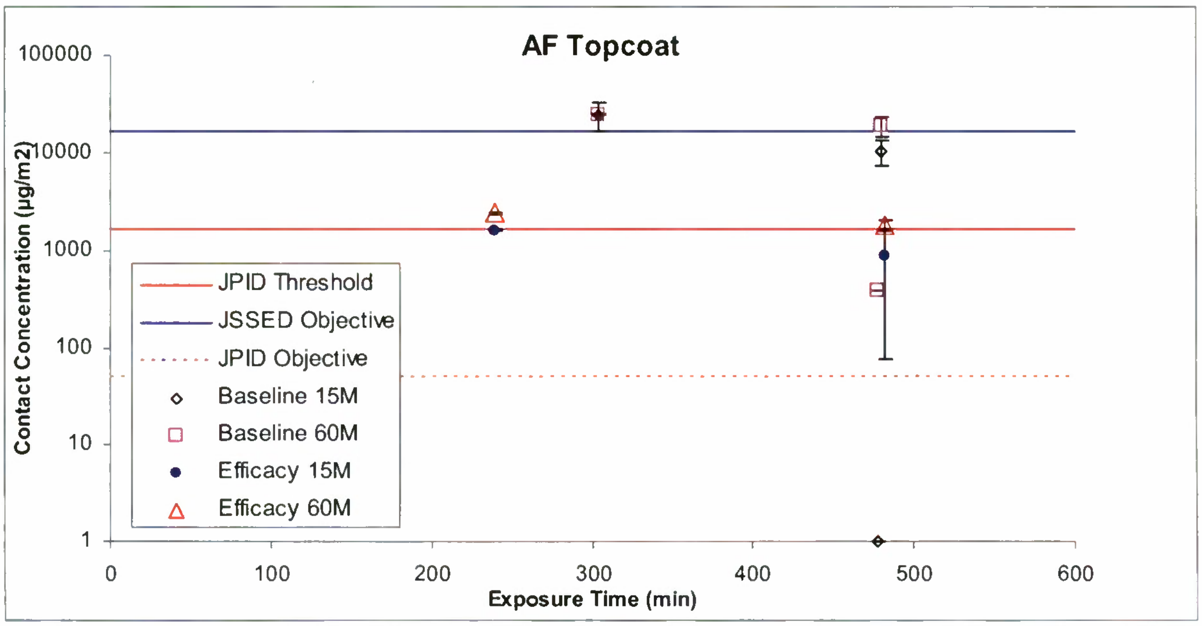


Figure 72. GD contact concentration vs. time for AF topcoat.

Table 108. GD 1 g/m² starting challenge contact test results for aluminum.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Aluminum	33	Baseline	15M	62	4/4	1677 ± 81	1.677 ± 0.081
Aluminum	26	Baseline	15M	118	4/4	456 ± 153	0.456 ± 0.153
Aluminum	26	Baseline	15M	304	4/4	297 ± 110	0.297 ± 0.110
Aluminum	4	Baseline	15M	477	3/3	0 ± 0	0.000 ± 0.000
Aluminum	5	Efficacy	15M	124	4/5	0 ± 0	0.000 ± 0.000
Aluminum	5	Efficacy	15M	234	5/5	1635 ± 54	1.635 ± 0.054
Aluminum	33	Baseline	60M	62	4/4	1209 ± 811	1.209 ± 0.811
Aluminum	26	Baseline	60M	118	4/4	131 ± 97	0.131 ± 0.097
Aluminum	26	Baseline	60M	304	4/4	118 ± 145	0.118 ± 0.145
Aluminum	4	Baseline	60M	477	3/3	0 ± 0	0.000 ± 0.000
Aluminum	5	Efficacy	60M	124	5/5	0 ± 0	0.000 ± 0.000
Aluminum	5	Efficacy	60M	234	5/5	906 ± 828	0.906 ± 0.828

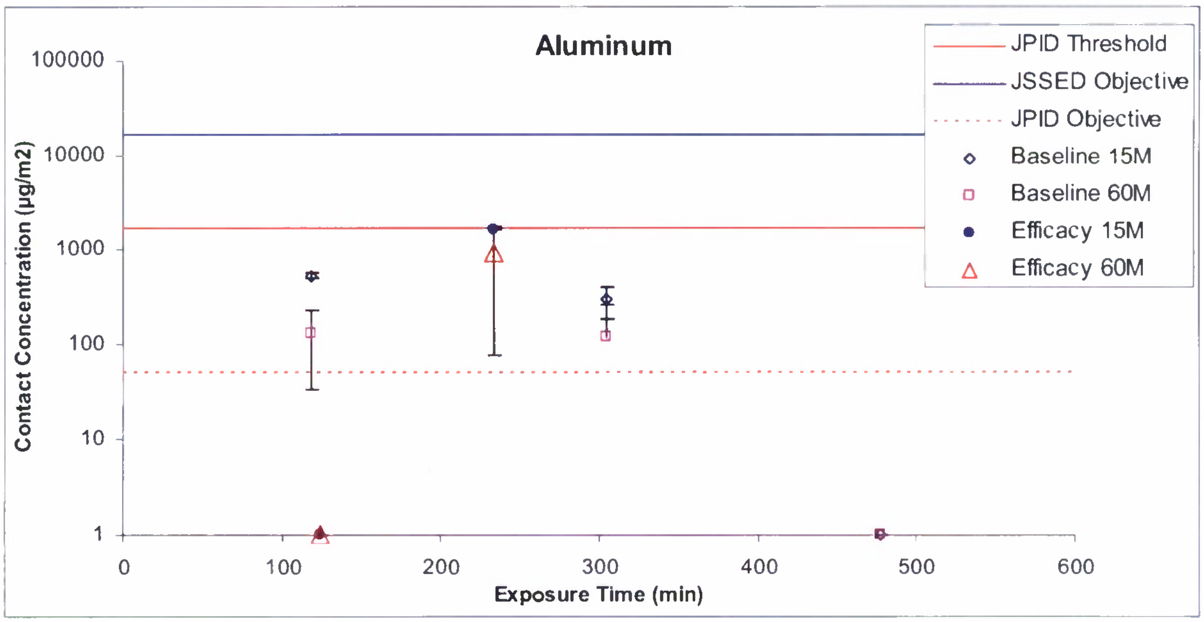


Figure 73. GD contact concentration vs. time for aluminum.

Table 109. GD 1 g/m² starting challenge contact test results for CARC.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (µg/m²)	GD Contact Concentration (mg/m²)
CARC	33	Baseline	15M	62	3/4	1809 ± 57	1.809 ± 0.057
CARC	26	Baseline	15M	118	4/4	926 ± 179	0.926 ± 0.179
CARC	26	Baseline	15M	304	4/4	953 ± 204	0.953 ± 0.204
CARC	4	Baseline	15M	477	3/3	0 ± 0	0.000 ± 0.000
CARC	26	Baseline	15M	480	4/4	528 ± 140	0.528 ± 0.140
CARC	3	Scoping	15M	62	4/4	0 ± 0	0.000 ± 0.000
CARC	3	Scoping	15M	180	4/4	0 ± 0	0.000 ± 0.000
CARC	6	Efficacy	15M	239	5/5	0 ± 0	0.000 ± 0.000
CARC	6	Efficacy	15M	482	4/5	0 ± 0	0.000 ± 0.000
CARC	33	Baseline	60M	62	4/4	1480 ± 1038	1.480 ± 1.038
CARC	26	Baseline	60M	118	3/4	1424 ± 140	1.424 ± 0.140
CARC	26	Baseline	60M	304	4/4	660 ± 223	0.660 ± 0.223
CARC	4	Baseline	60M	477	3/3	0 ± 0	0.000 ± 0.000
CARC	26	Baseline	60M	480	4/4	490 ± 313	0.490 ± 0.313
CARC	3	Scoping	60M	62	4/4	0 ± 0	0.000 ± 0.000
CARC	3	Scoping	60M	180	3/4	0 ± 0	0.000 ± 0.000
CARC	6	Efficacy	60M	239	4/5	1650 ± 148	1.650 ± 0.148
CARC	6	Efficacy	60M	482	5/5	0 ± 0	0.000 ± 0.000

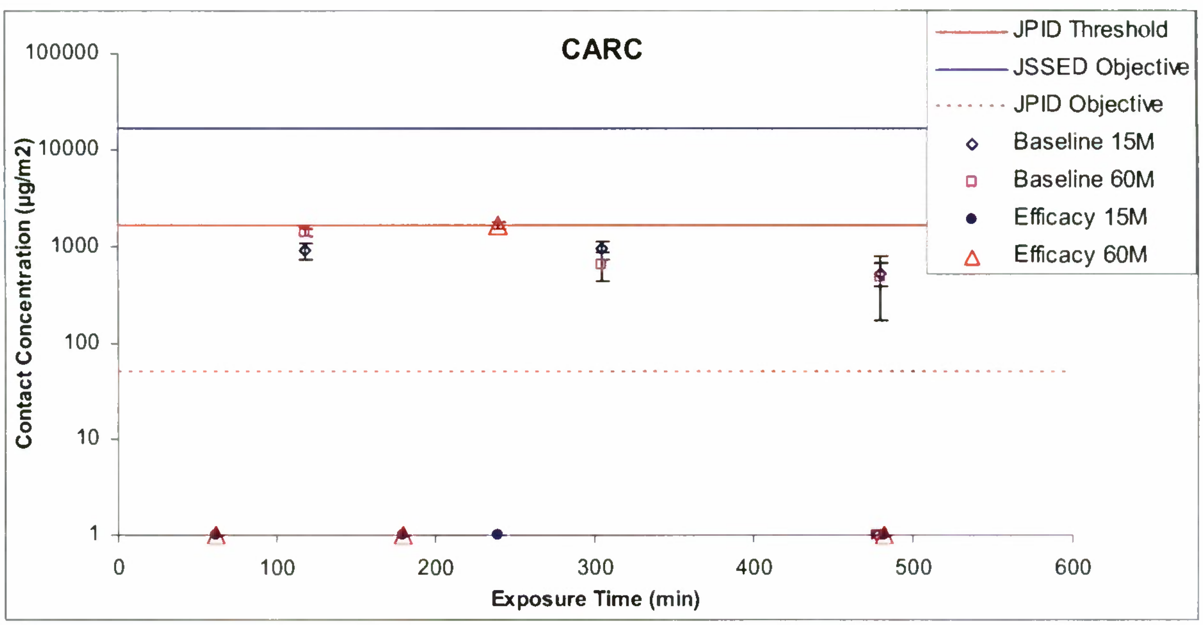


Figure 74. GD contact concentration vs. time for CARC.

Table 110. GD 1 g/m² starting challenge hazard contact results for glass.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Glass	33	Baseline	15M	62	4/4	814 ± 941	0.814 ± 0.941
Glass	26	Baseline	15M	118	4/4	662 ± 156	0.662 ± 0.156
Glass	26	Baseline	15M	304	4/4	356 ± 101	0.356 ± 0.101
Glass	4	Baseline	15M	477	3/3	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	15M	62	4/4	2906 ± 912	2.906 ± 0.912
Glass	5	Efficacy	15M	124	5/5	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	15M	180	4/4	0 ± 0	0.000 ± 0.000
Glass	5	Efficacy	15M	234	5/5	906 ± 828	0.906 ± 0.828
Glass	33	Baseline	60M	62	4/4	789 ± 911	0.789 ± 0.911
Glass	26	Baseline	60M	118	4/4	122 ± 92	0.122 ± 0.092
Glass	26	Baseline	60M	304	4/4	100 ± 70	0.100 ± 0.070
Glass	4	Baseline	60M	477	3/3	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	60M	62	4/4	1429 ± 171	1.429 ± 0.171
Glass	5	Efficacy	60M	124	5/5	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	60M	180	4/4	4261 ± 2931	4.261 ± 2.931
Glass	5	Efficacy	60M	234	4/5	0 ± 0	0.000 ± 0.000

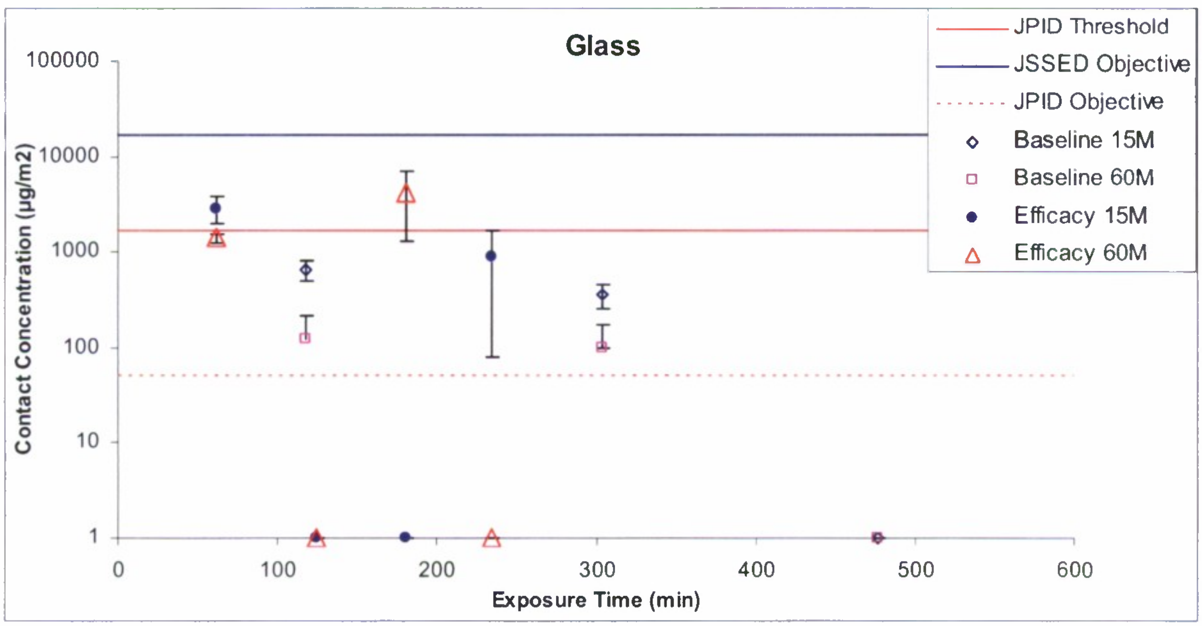


Figure 75. GD contact concentration vs. time for glass.

Table 111. GD 1 g/m² starting challenge contact test results for Kapton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Kapton	26	Baseline	15M	118	4/4	397 ± 226	0.397 ± 0.226
Kapton	26	Baseline	15M	304	4/4	458 ± 129	0.458 ± 0.129
Kapton	4	Baseline	15M	477	3/3	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	15M	124	5/5	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	15M	234	5/5	1537 ± 54	1.537 ± 0.054
Kapton	26	Baseline	60M	118	4/4	141 ± 110	0.141 ± 0.110
Kapton	26	Baseline	60M	304	4/4	179 ± 182	0.179 ± 0.182
Kapton	4	Baseline	60M	477	3/3	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	60M	124	5/5	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	60M	234	4/5	1453 ± 49	1.453 ± 0.049

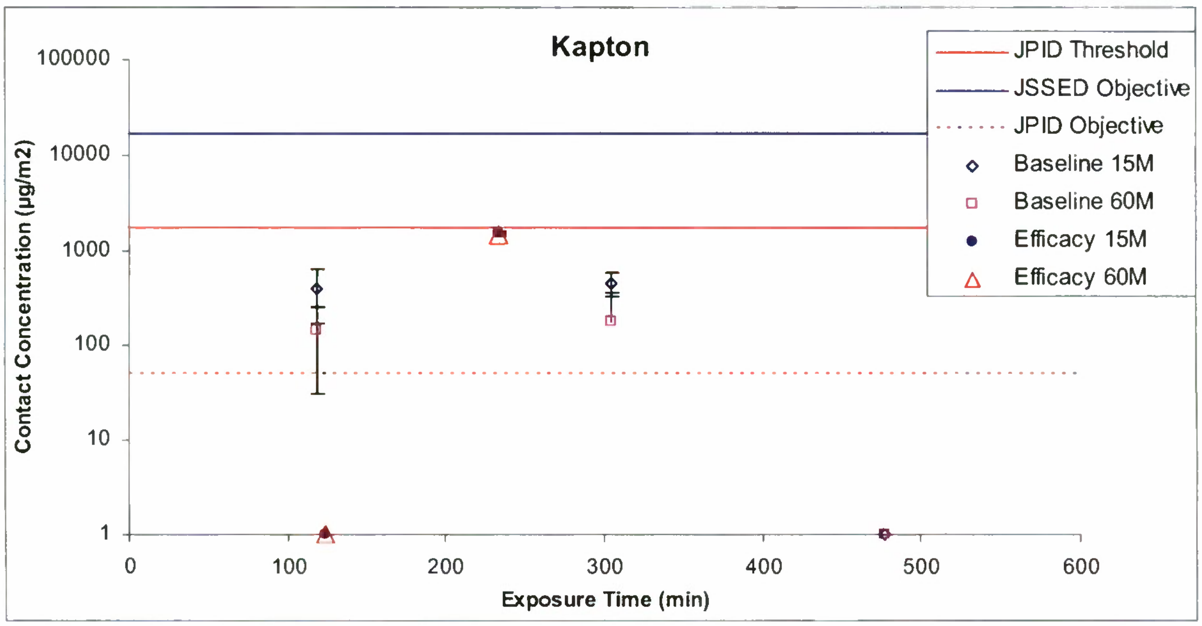


Figure 76. GD contact concentration vs. time for Kapton.

Table 112. GD 1 g/m² starting challenge contact test results for polycarbonate.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Polycarb.	33	Baseline	15M	62	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	26	Baseline	15M	118	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	26	Baseline	15M	304	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	4	Baseline	15M	477	3/3	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	15M	62	4/4	1626 ± 459	1.626 ± 0.459
Polycarb.	5	Efficacy	15M	124	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	15M	180	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	5	Efficacy	15M	234	4/5	0 ± 0	0.000 ± 0.000
Polycarb.	33	Baseline	60M	62	3/4	0 ± 0	0.000 ± 0.000
Polycarb.	26	Baseline	60M	118	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	26	Baseline	60M	304	4/4	60 ± 70	0.060 ± 0.070
Polycarb.	4	Baseline	60M	477	3/3	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	60M	62	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	5	Efficacy	60M	124	5/5	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	60M	180	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	5	Efficacy	60M	234	4/5	0 ± 0	0.000 ± 0.000

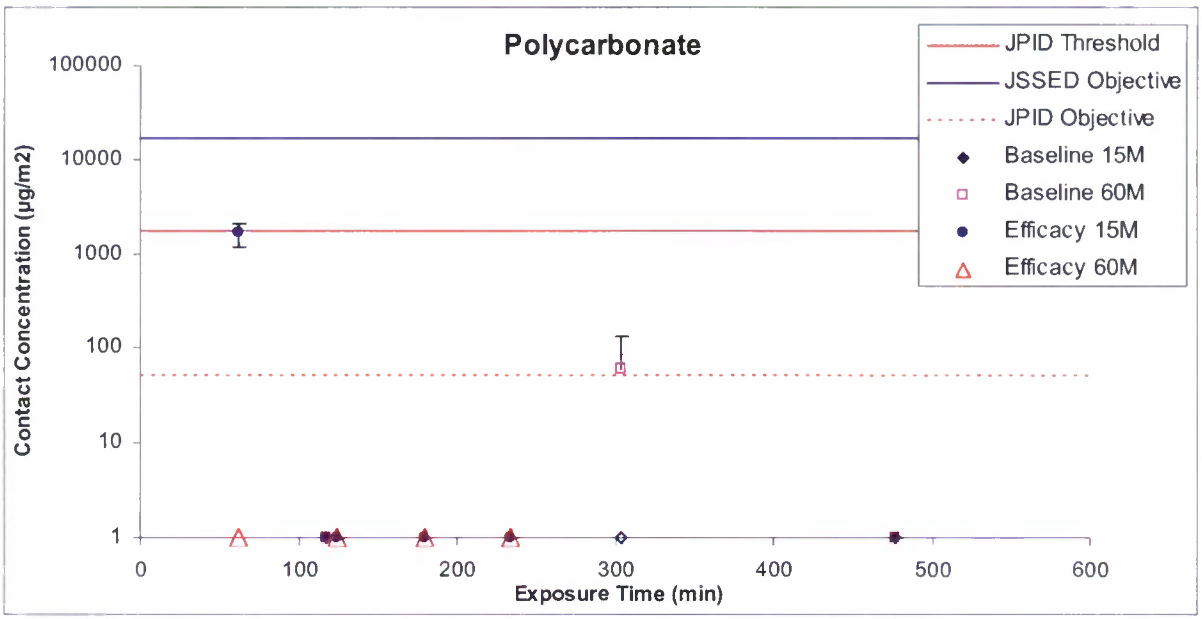


Figure 77. GD contact concentration vs. time for polycarbonate.

Table 113. GD 1 g/m² starting challenge contact test results for silicone.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Silicone	4	Baseline	15M	477	3/3	952 ± 373	0.952 ± 0.373
Silicone	26	Baseline	15M	480	4/4	5405 ± 1027	5.405 ± 1.027
Silicone	3	Scoping	15M	62	4/4	12906 ± 1450	12.906 ± 1.450
Silicone	3	Scoping	15M	180	4/4	10690 ± 1814	10.690 ± 1.814
Silicone	6	Efficacy	15M	239	5/5	4690 ± 1334	4.690 ± 1.334
Silicone	6	Efficacy	15M	482	5/5	2700 ± 398	2.700 ± 0.398
Silicone	4	Baseline	60M	477	3/3	2496 ± 602	2.496 ± 0.602
Silicone	26	Baseline	60M	480	4/4	13711 ± 2472	13.711 ± 2.472
Silicone	3	Scoping	60M	62	4/4	20172 ± 1591	20.172 ± 1.591
Silicone	3	Scoping	60M	180	3/4	17931 ± 1258	17.931 ± 1.258
Silicone	6	Efficacy	60M	239	5/5	250246 ± 349938	250.246 ± 349.938
Silicone	6	Efficacy	60M	482	4/5	5493 ± 246	5.493 ± 0.246

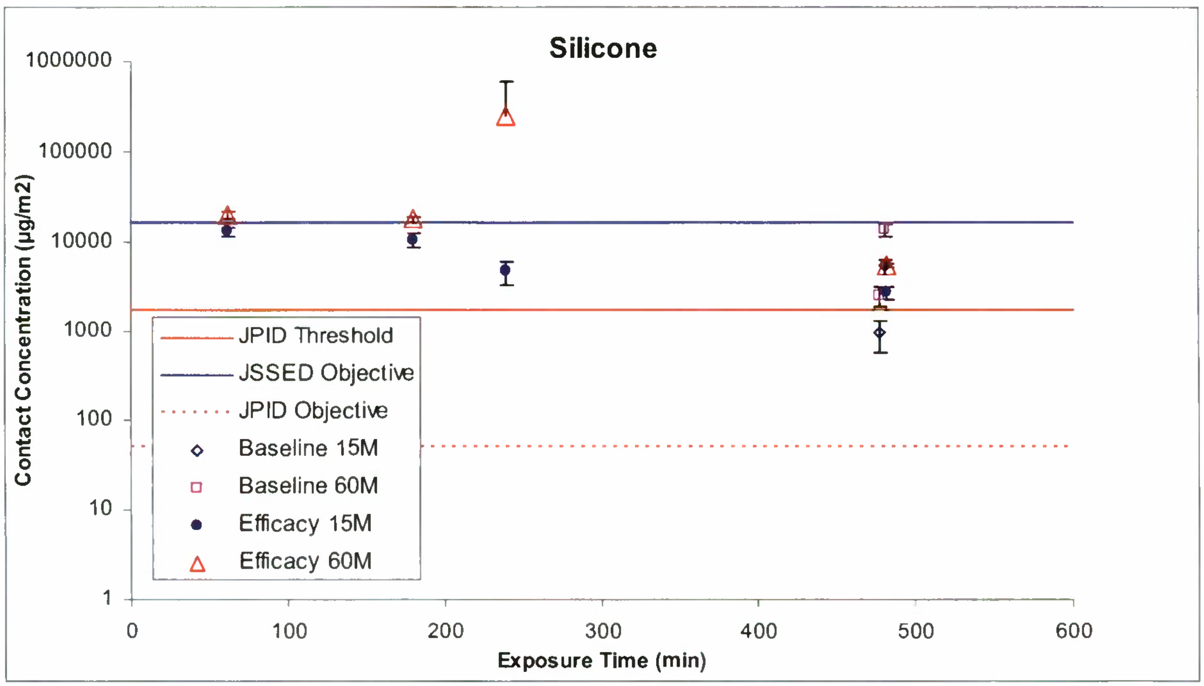


Figure 78. GD contact concentration vs. time for silicone.

Table 114. GD 1 g/m² starting challenge contact test results for Viton.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Viton	4	Baseline	15M	477	3/3	1511 ± 444	1.511 ± 0.444
Viton	26	Baseline	15M	480	4/4	10984 ± 449	10.984 ± 0.449
Viton	6	Efficacy	15M	239	5/5	3350 ± 478	3.350 ± 0.478
Viton	6	Efficacy	15M	482	5/5	2128 ± 149	2.128 ± 0.149
Viton	4	Baseline	60M	477	3/3	3317 ± 506	3.317 ± 0.506
Viton	26	Baseline	60M	480	4/4	17317 ± 4990	17.317 ± 4.990
Viton	6	Efficacy	60M	239	5/5	156532 ± 203520	156.532 ± 203.520
Viton	6	Efficacy	60M	482	5/5	3961 ± 805	3.961 ± 0.805

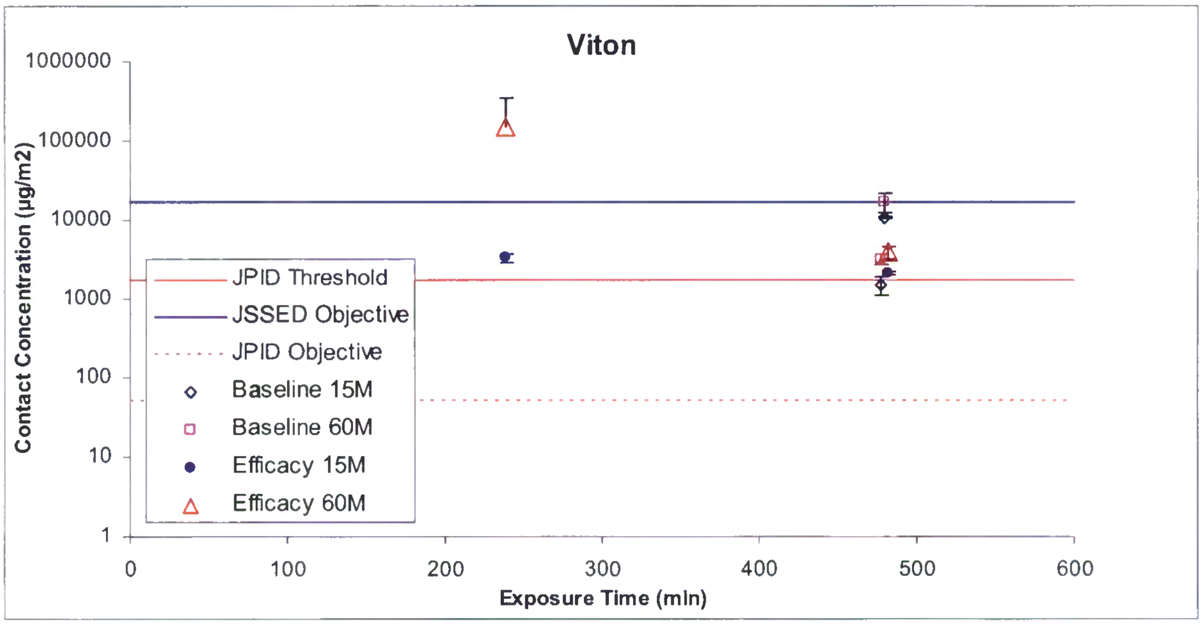


Figure 79. GD contact concentration vs. time for Viton.

Table 115. GD 1 g/m² starting challenge contact test residual agent results for all materials.

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
AF topcoat	26	Baseline	RES	304	4/4	351 ± 64	0.351 ± 0.064
AF topcoat	4	Baseline	RES	477	3/3	250 ± 57	0.250 ± 0.057
AF topcoat	26	Baseline	RES	480	4/4	256 ± 178	0.256 ± 0.178
AF topcoat	6	Efficacy	RES	239	4/5	71 ± 4	0.071 ± 0.004
AF topcoat	6	Efficacy	RES	482	5/5	52 ± 15	0.052 ± 0.015
Aluminum	33	Baseline	RES	62	4/4	0 ± 0	0.000 ± 0.000
Aluminum	26	Baseline	RES	118	3/4	0 ± 0	0.000 ± 0.000
Aluminum	26	Baseline	RES	304	3/4	0 ± 0	0.000 ± 0.000
Aluminum	4	Baseline	RES	477	3/3	0 ± 0	0.000 ± 0.000

Table 115. GD 1 g/m² starting challenge contact test residual agent results for all materials (continued).

Material	Run	Run Type	Test Set	Exp. Time (min)	Reps	GD Contact Concentration (μg/m²)	GD Contact Concentration (mg/m²)
Aluminum	5	Efficacy	RES	124	5/5	0 ± 0	0.000 ± 0.000
Aluminum	5	Efficacy	RES	234	5/5	0 ± 0	0.000 ± 0.000
CARC	33	Baseline	RES	62	4/4	26 ± 20	0.026 ± 0.020
CARC	26	Baseline	RES	118	4/4	8 ± 2	0.008 ± 0.002
CARC	26	Baseline	RES	304	4/4	6 ± 2	0.006 ± 0.002
CARC	4	Baseline	RES	477	3/3	1 ± 0	0.001 ± 0.000
CARC	26	Baseline	RES	480	3/4	4 ± 0	0.004 ± 0.000
CARC	3	Scoping	RES	62	4/4	2 ± 1	0.002 ± 0.001
CARC	3	Scoping	RES	180	4/4	2 ± 1	0.002 ± 0.001
CARC	6	Efficacy	RES	239	5/5	1 ± 1	0.001 ± 0.001
CARC	6	Efficacy	RES	482	5/5	1 ± 0	0.001 ± 0.000
Glass	33	Baseline	RES	62	4/4	0 ± 0	0.000 ± 0.000
Glass	26	Baseline	RES	118	4/4	0 ± 0	0.000 ± 0.000
Glass	26	Baseline	RES	304	4/4	0 ± 0	0.000 ± 0.000
Glass	4	Baseline	RES	477	3/3	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	RES	62	4/4	7 ± 4	0.007 ± 0.004
Glass	5	Efficacy	RES	124	5/5	0 ± 0	0.000 ± 0.000
Glass	3	Scoping	RES	180	4/4	0 ± 0	0.000 ± 0.000
Glass	5	Efficacy	RES	234	5/5	0 ± 0	0.000 ± 0.000
Kapton	26	Baseline	RES	118	4/4	84 ± 111	0.084 ± 0.111
Kapton	26	Baseline	RES	304	4/4	67 ± 78	0.067 ± 0.078
Kapton	4	Baseline	RES	477	3/3	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	RES	124	5/5	0 ± 0	0.000 ± 0.000
Kapton	5	Efficacy	RES	234	5/5	1 ± 1	0.001 ± 0.001
Polycarb.	33	Baseline	RES	62	3/4	1 ± 0	0.001 ± 0.000
Polycarb.	26	Baseline	RES	118	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	26	Baseline	RES	304	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	4	Baseline	RES	477	3/3	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	RES	62	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	5	Efficacy	RES	124	4/5	0 ± 0	0.000 ± 0.000
Polycarb.	3	Scoping	RES	180	4/4	0 ± 0	0.000 ± 0.000
Polycarb.	5	Efficacy	RES	234	5/5	1 ± 1	0.001 ± 0.001
Silicone	4	Baseline	RES	477	3/3	325 ± 117	0.325 ± 0.117
Silicone	26	Baseline	RES	480	3/4	418 ± 42	0.418 ± 0.042
Silicone	3	Scoping	RES	62	4/4	0 ± 0	0.000 ± 0.000
Silicone	3	Scoping	RES	180	4/4	0 ± 0	0.000 ± 0.000
Silicone	6	Efficacy	RES	239	5/5	131 ± 172	0.131 ± 0.172
Silicone	6	Efficacy	RES	482	5/5	327 ± 91	0.327 ± 0.091
Viton	4	Baseline	RES	477	3/3	266 ± 71	0.266 ± 0.071
Viton	26	Baseline	RES	480	4/4	323 ± 67	0.323 ± 0.067
Viton	6	Efficacy	RES	239	5/5	220 ± 200	0.220 ± 0.200
Viton	6	Efficacy	RES	482	5/5	334 ± 111	0.334 ± 0.111

10.5 Contact Test Results Compared to ORDs for GD 1 g/m² Starting Challenge

The specified GD ORD values for JPID and JSSED are provided in Table 116. The post-decontamination vapor test data for the approximately 1 g/m² GD starting challenge was directly compared to the ORD contact hazard values and presented in Table 117.

The ORD factors are provided in the table for quick comparison to the requirements. An ORD Factor value ≤1.0 passes the ORD; a value >1.0 fails to meet the ORD. Note that only efficacy run types are presented in the ORD evaluation (i.e., scoping data is not presented here). The Table 117 results are summarized in the following list.

- **AF topcoat** was a factor of 36 times the JPID objective ORD after 482 min of decontamination.
- **Aluminum** was a factor of 33 times the JPID objective ORD after 234 min of decontamination.
- **CARC** met the JPID objective factor after 62 min of decontamination.
- **Glass** was a factor of 18 times the JPID objective ORD after 234 min of decontamination. However, several tests at shorter time points exhibited complete decontamination.
- **Kapton** was a factor of 30 times the JPID objective ORD after 234 min of decontamination. However, several tests at shorter time points exhibited complete decontamination.
- **Polycarbonate** met the JPID objective factor after 124 min of decontamination.
- **Silicone** was a factor of 110 times the JPID objective ORD after 482 min of decontamination.
- **Viton** was a factor of 79 times the JPID objective ORD after 482 min of decontamination.

The JSSED ORD values specify a 10 g/m² starting challenge. The data presented here corresponds to a 1 g/m² starting challenge. It has not yet been proven that a pre-wipe can effectively reduce the starting contamination from 10 g/m² to 1 g/m² for all materials tested. A 90% reduction in starting challenge, as demonstrated by comparing the 1 g/m² data to the JSSED ORD values, was achieved with a pre-wipe or other immediate decontamination process. If the wipe performance is validated, then this 1 g/m² data may be sufficient to evaluate the mVHP technology against both requirements, with the caveat that the higher JSSED contamination density challenge would require the incorporation of a pre-wipe method.

Table 116. Contact ORD values for GD.

ORD	Starting Challenge (g/m²)	GD Contact Concentration (µg/m²)	GD Contact Concentration (mg/m²)
JPID Threshold	1	1700	1.7
JPID Objective	1	0* (50)	0.0* (0.05)
JSSED Threshold	N/A	N/A	N/A
JSSED Objective	10	16700	16.7

* This value was set as 0.0 mg/m² in the ORD. Since the values are reported as zeroes, mathematically statistical comparisons are not possible. A non-significant digit was added after the zeroes to enable mathematical treatment of the data. The use of this value does not change the significant figures associated with the ORD value. Agent concentrations greater than 0.05 mg/m² (when rounded to the presented accuracy would return a result of 0.1 mg/m²) fail the JPID objective level.

Table 117. GD 1 g/m² starting challenge contact test results compared to ORD.

Material	Exp. Time (min)	Test Set	GD Contact Concentration (mg/m²)	JPID Threshold Factor	JSSED Objective. Factor	JPID Objective. Factor
AF topcoat	239	15M	1.626 ± 0.057	0.96	0.10	32.51
		60M	2.414 ± 0.057	1.42	0.14	48.28
	482	15M	0.887 ± 0.809	0.52	0.05	17.73
		60M	1.833 ± 0.227	1.08	0.11	36.65
Aluminum	124	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	234	15M	1.635 ± 0.054	0.96	0.10	32.71
		60M	0.906 ± 0.828	0.53	0.05	18.13
CARC	62	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	180	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	239	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	1.650 ± 0.148	0.97	0.10	33.00
	482	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Glass	62	15M	2.906 ± 0.912	1.71	0.17	58.13
		60M	1.429 ± 0.171	0.84	0.09	28.57
	124	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	180	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	4.261 ± 2.931	2.51	0.26	85.22
	234	15M	0.906 ± 0.828	0.53	0.05	18.13
		60M	0.000 ± 0.000	0.00	0.00	0.00
Kapton	124	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	234	15M	1.537 ± 0.054	0.90	0.09	30.74
		60M	1.453 ± 0.049	0.85	0.09	29.06
Polycarb.	62	15M	1.626 ± 0.459	0.96	0.10	32.51
		60M	0.000 ± 0.000	0.00	0.00	0.00
	124	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	180	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
	234	15M	0.000 ± 0.000	0.00	0.00	0.00
		60M	0.000 ± 0.000	0.00	0.00	0.00
Silicone	62	15M	12.906 ± 1.450	7.59	0.77	258.13
		60M	20.172 ± 1.591	11.87	1.21	403.45
	180	15M	10.690 ± 1.814	6.29	0.64	213.79
		60M	17.931 ± 1.258	10.55	1.07	358.62
	239	15M	4.690 ± 1.334	2.76	0.28	93.79
		60M	250.246 ± 349.938	147.20	14.98	5004.93
	482	15M	2.700 ± 0.398	1.59	0.16	53.99
		60M	5.493 ± 0.246	3.23	0.33	109.85
Viton	239	15M	3.350 ± 0.478	1.97	0.20	67.00
		60M	156.532 ± 203.520	92.08	9.37	3130.64
	482	15M	2.128 ± 0.149	1.25	0.13	42.56
		60M	3.961 ± 0.805	2.33	0.24	79.21

11. CHALLENGES AND LESSONS LEARNED

11.1 Challenging Test Conditions and Materials

The test, as designed, included a range of materials differing in composition and porosity. Non-sorptive materials, such as bare aluminum and glass, were traditionally used. Polycarbonate and Kapton were used to represent plastics and electrical sheathing. CARC- and AF Topcoat-coated metal provided information regarding coated metal surfaces. Finally, the adsorptive materials silicone and Viton were used to represent gasket and other flexible materials. Non-sorptive materials are generally easier to decontaminate. The study of adsorptive materials posed additional challenges for decontaminants. Evaluation tests needed to evaluate representative materials from different classes (i.e., metals, plastics, glass and adsorptive materials such as silicone), to best understand the strengths and limitations of a particular decontaminant. The selection of the wide range of materials in this evaluation was viewed as a positive learning tool. The material challenges are discussed further in Section 11.8. The need for test article methods is discussed in Section 11.5.

11.2 Improved Test Design

The 2005 test program used an improved test design compared with the 2004 test program. The 2004 chamber test, discussed in Section 11.9, was the first large chemical agent efficacy test. The 2004 program did not have a detailed test plan enabling traceability of the testing. The 2005 test program benefited from a detailed test plan that specified the types of testing, use of statistical replicates, cross-contamination blanks, coupon treatment methods, and analytical methods. The JPEO-CBD JPM Decon staff participated in the development of the test plan. Test types such as baseline (i.e., weathering control) were conducted to provide additional information regarding decontamination efficacy. The enclosure for the 2005 program was built to simulate one of the mVHP systems as a more accurate evaluation of the technology.

11.3 mVHP Technology Optimization

The mVHP systems have significantly improved over the past few years. The newer systems have demonstrated higher treatment concentrations and improved process control. As a result, the newer systems have shorter decontamination treatment times (Figure 80). The methods for creating and delivering the fumigant, and the process conditions have not been optimized to determine the most effective (i.e., shortest treatment time) and efficient (i.e., lowest logistical burden) decontamination process.

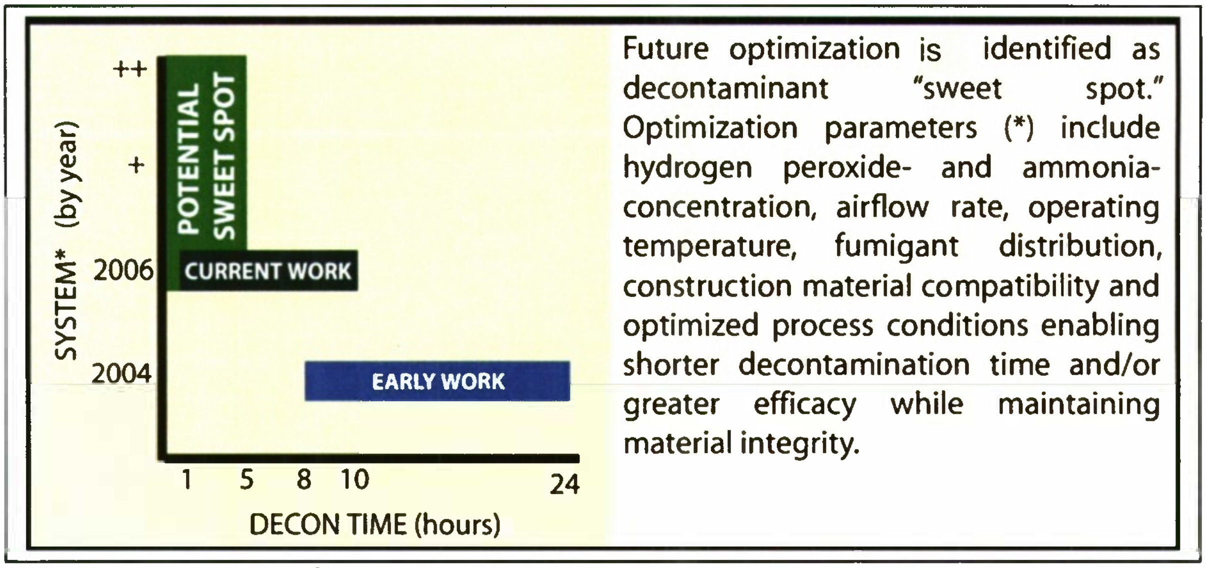


Figure 80. Representation of mVHP sweet spot with optimization.

The technology evaluated did not have a rinse step following treatment. Any non-volatile reaction products remained on the surface following treatment. The use of higher treatment temperatures and flow rates during system optimization could have yielded cleaner surfaces by volatilizing agent and byproducts. The proposed study of combined mVHP and Forced Hot Air would look at the potential for reducing surface residual requiring, at most, only spot cleaning post treatment.

11.4 Methods Improvement – Coupon Testing

In addition to the low-level method improvement, the standard method for decontaminant testing TOP 8-2-061 needed some modification. As written, the TOP allowed for a lot of flexibility, which is acceptable for early Research and Development (R&D) efforts. However, as efforts moved into late R&D and pre-acquisition, the ability to compare data between laboratories was needed. In a DTRA – T&E funded effort between ECBC and DPG, the TOP 8-2-061 was improved to add rigor to vague steps. The end product was a set of rigorous methods that, when used, enable direct comparison of data between different laboratories.

11.5 Methods Improvement – Equipment Testing

At some point during R&D, the application of a new decontaminant technology to actual field items was needed. Real items were constructed from materials similar to the coupon materials studied. However, the actual test articles had additional challenges such as seams between material types, and resultant "nooks and crannies," non-flat surfaces, and protective coatings (i.e., anti-glare and anti-scratch). An attempt was made during the last VX run to evaluate DVD player screens and casings. The DVD players had the largest flat surface area for study. A grease pencil was used to mark a 2 in. circular test region on the screens (Figure 81) and DVD casing. Figure 81 shows the treatment cycle of the four DVD players studied (note, the camera could not clearly photograph E01 in the mVHP box, so a photo for E02 is shown). The DVD players were analyzed for the 15 and 60 min contact test. The results are shown in Table 118 and Table 119 for this scoping test. Overall, the first test appeared to show a substantial reduction in VX. The data was recovered from the CCV failure, so the absolute values and associated error was not certain. In addition, this was a different solvent than that used for the coupon testing (Section 11.11). Since this was a test to demonstrate methodology needs, the use of baseline (positive) controls was not conducted. Image analysis of the contaminated screen on DVD player E01

(Figure 81 upper left, dashed circle), compared with post-mVHP exposure (Figure 81 bottom right, dashed circle) shows a reduction in agent.

A recommendation for future testing is a collaborative effort, under the support of the Joint Program Management (JPM) (i.e., Decon), between the acquisition program staff (i.e., Project Management [PM], engineering, and Joint Material Decontamination System [JMDS]), the R&D testing staff (i.e., ECBC), and the demonstration testing staff (i.e., Dugway Proving Ground [DPG]) to take existing methods for test articles and create a reference test article protocol applicable to all stages of testing.

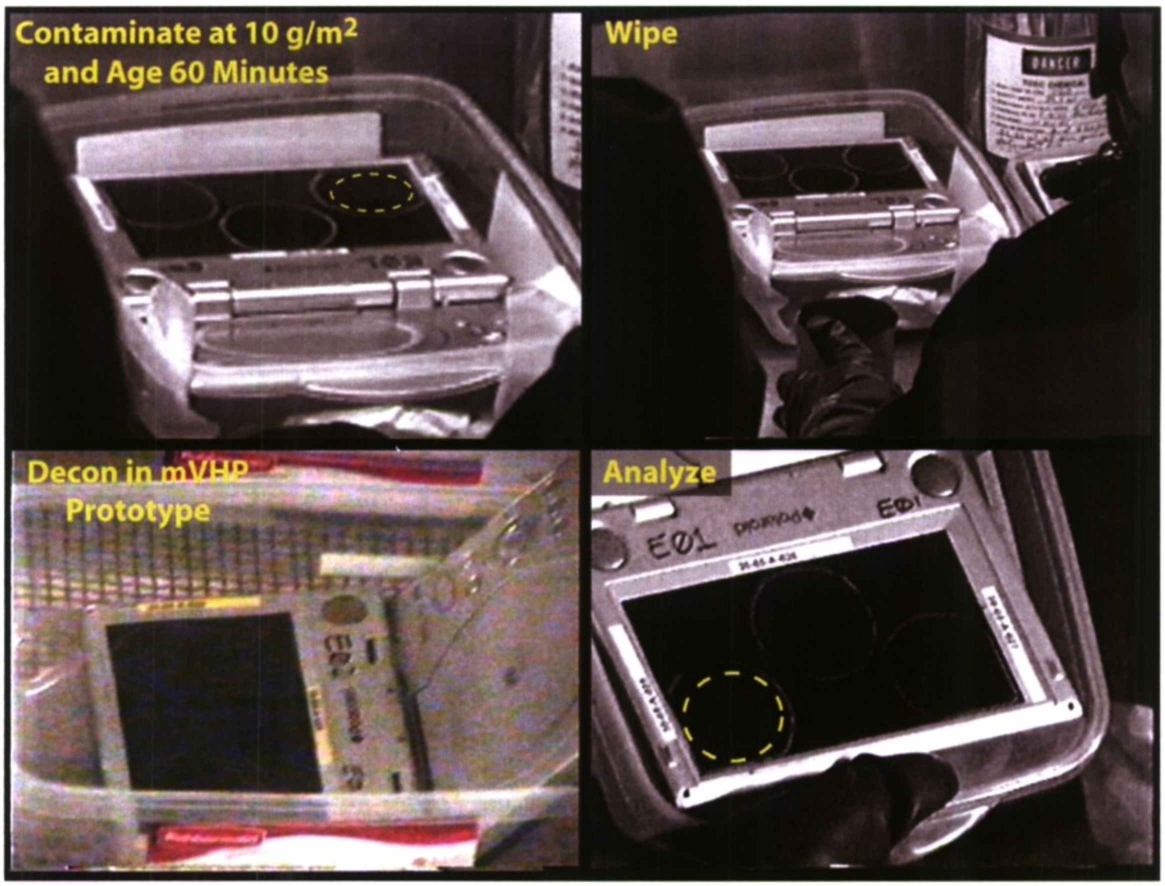


Figure 81. Method development for actual articles and live-agent testing.

Table 118. Contact test results for VX 10 g/m² starting challenge with pre-wipe and mVHP on a DVD player.

Material	Exp. Time (min)	Wipe	Run	Run Type	Test Set	Reps	VX Contact Conc. (μg/m²)	VX Contact Conc. (mg/m²)
DVD Screen	360	Yes	30	Efficacy	15M	6/6	269 ± 48‡	0.269 ± 0.048‡
					60M	6/6	113 ± 27‡	0.113 ± 0.027‡
DVD Cover	360	Yes	30	Efficacy	15M	6/6	295 ± 72‡	0.295 ± 0.072‡
					60M	6/6	93 ± 23‡	0.093 ± 0.023‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

Table 119. Comparison to ORD for contact test results for VX 10 g/m² starting challenge with pre-wipe and mVHP on a DVD player.

Material	Exp. Time (min)	Wipe	Run	Run Type	Test Set	VX Contact Conc. (mg/m²)	JSSED Objective
DVD Screen	360	Yes	30	Efficacy	15M 60M	0.269 ± 0.048‡ 0.113 ± 0.027‡	0.35‡ 0.15‡
DVD Cover	360	Yes	30	Efficacy	15M 60M	0.295 ± 0.072‡ 0.093 ± 0.023‡	0.38‡ 0.12‡

‡ - CCV failed – data recovered using single point calibration of CCV; data is suspect.

11.6 When to Apply the Pre-Wipe

The pre-wipe step was performed after contamination and 60 min-aging period, and before placement in the mVHP box. Since the pre-wipe is intended as an immediate decontamination, a better application of the pre-wipe would have been after a shorter 15 min-aging period. The longer aging period allowed more adsorption of agent into porous substrates such as silicone. The result was larger residual agent values than would be expected, if immediate decontamination was performed. The 60 min-aging period used in this test would be a worst-case scenario, if immediate decontamination could not occur.

11.7 Warm versus Ambient Baseline Test

The first baseline test used the mVHP system and removed only hydrogen peroxide and ammonia. The mVHP decontamination technology, however, was a combination of hydrogen peroxide, ammonia, distribution, temperature, and humidity. Removing only two of the technology components was not a representative test. By removing hydrogen peroxide and ammonia, the baseline test at operating temperature was a forced "warm-air" test. The data showed that agent was removed from the surface, but without a decontaminant, the contamination was only moved downstream. Forced hot air is a decontamination approach for removing agent from area of interest and collecting the contamination on a filter system. The "warm" baseline mimicked that type of test. Ambient-condition baseline tests were conducted as a positive control, showing the contribution of the mVHP process to agent decontamination. The ambient baseline tests removed four of the five mVHP process components—hydrogen peroxide, ammonia, temperature, and humidity. Airflow was maintained to ensure that a static state did not develop in the decontamination chamber.

11.8 Material Observations and Other Comparisons

A program objective was to evaluate the technology and the capability for the decontamination of chemical agent on military-relevant surfaces. This report focuses solely on the comparison to ORD. The data set collected was large and diverse, enabling many other initial comparisons, which may have value in future efforts. The data shows that the mVHP capability was not necessarily agent dependent, but agent-material dependent. The 1 and 10 g/m² starting challenges are visible drops when initially applied to the surface. The agent may spread and adsorb or remain as droplets, depending on the surface.

11.9 2004 Chamber Test

In 2004, a chamber test similar in concept to this test was conducted; however, this test used 250 ppm hydrogen peroxide and 15 ppm ammonia concentrations. The program did not use a detailed test plan to facilitate planning and data needs. Some of the techniques that were new to this test included statistical replicates, cross-contamination blanks, coupon chain of custody, and detailed record keeping. The test provided proof-of-concept that chemical agent could be decontaminated on a scale larger than that implemented in the laboratory. Highlights from the test and lessons learned are discussed in this section.

The test chamber was designed based on the room model, following the building demonstration. A 1000 ft^3 enclosure was constructed from aluminum framing and covered with polyethylene sheeting. Enclosure access areas included a door and a sample slot. The sample slot was used for quick sample placement and removal. A single M1000 VHP generator, modified for ammonia use, was originally connected to the chamber. The single generator had difficulty maintaining the target fumigant concentration during early tests. A second M1000 generator was added in line to increase fumigation system capacity. The enclosure was not leak proof, resulting in loss of fumigant during testing. This loss impacts both fumigant distribution and raw material consumption.

The number of samples used for each test day was dependent on analytical throughput. Statistical replicates were not used within a test set; instead, three runs at the same conditions were run using one coupon per run. This approach, however, was further complicated because hydrogen peroxide and ammonia concentrations, temperature, and humidity were not reproducible between tests, which added additional spread to the data. Using statistical replicates within a run, and evaluating different materials in each run would be recommended.

The fumigant concentrations were 275 ppm hydrogen peroxide and 20 ppm ammonia, which was slightly different than the demonstration work. In addition, the amount of ammonia varied between runs. The samples were evaluated for both contact and vapor hazard. Baseline tests and cross-contamination blanks were not utilized.

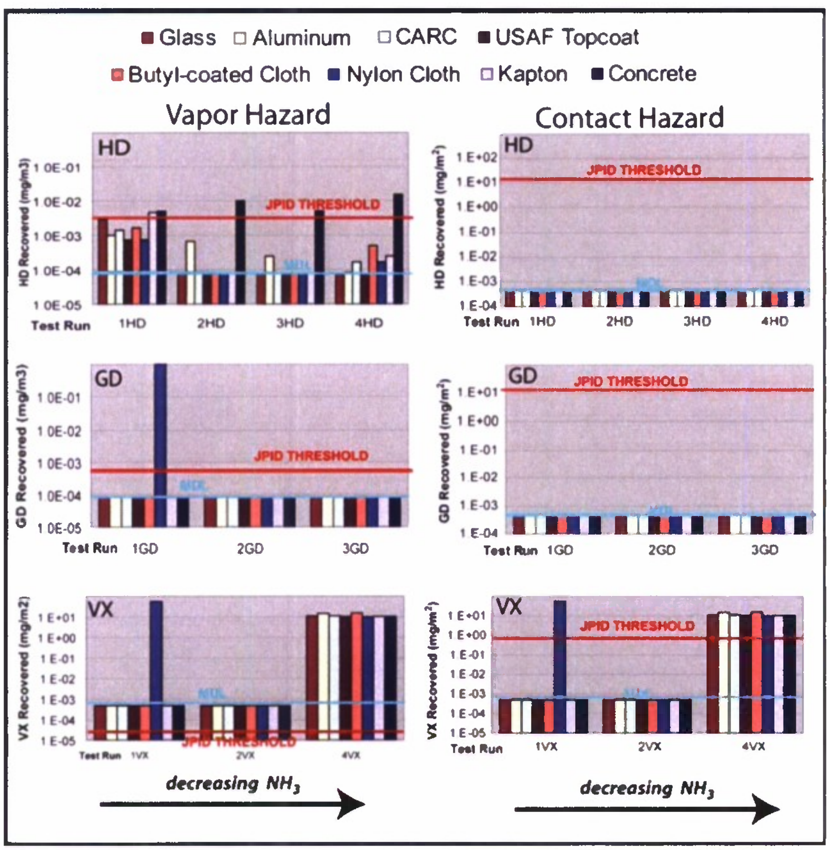


Figure 82. 2004 Chamber test results show longer treatment times.

The project records do not contain information regarding analytical methodology, including calibration ranges, and the use of Initial Calibration Verification (ICV) or CCV. A Method Detection Limit (MDL) was provided for each agent, but it is uncertain if the low-end calibration range was at that limit. The analytical methodology was needed to verify the test results.

This test showed that the required treatment time for HD, GD, TGD, and VX was between 8 and 24 h (Figure 82) at the lower treatment concentrations of 275 ppm hydrogen peroxide and 20 ppm ammonia. The current data shows that treatment time is significantly shorter using a higher treatment concentration and improved air distribution.

11.10 Low-End VX Calibration Challenge

Unanticipated problems still occurred during testing despite detailed test design and project planning meetings. The major lesson learned regarded analytical testing. The ORD KPPs specify a low VX concentration for the contact hazard. During the planning meetings, the test personnel indicated that the concentration range was doable using the existing methods. In hindsight, the test director should have had the method verified with a demonstration. The existing method was unable to reach the VX objective ORD concentration, making a comparison to ORD impossible. The issue was not preparation of the standards, but rather, the ability to hold calibration, as indicated by CCV failures. The analytical technical person did attempt to remedy the situation using numerous approaches and reruns. The values were reported to pass CCV. The values associated with failed CCV samples were corrected using a published method, and indicated with suspect data flags (as discussed in Section 2.12.3) to demonstrate potential to meet ORD. Based on this result, the development of rigorous test methods within the Decontamination Sciences Team was initiated. The development and validation of the techniques for low-level (i.e., at and below ORD KPP level) determination was a DTRA-funded effort.

11.11 Extraction Solvent Selection

The selection of solvent was especially important for the residual-agent measurements. Various solvents showed a different efficiency for the removal of agent from the coupon surface. The values reported herein for the residual agent were not corrected for extraction efficiency. Since there was no ORD for residual agent, the values for both the extraction efficiency and efficacy test are provided.

Methylene chlorine was used as a solvent in run 17R to determine whether the CCV failures encountered during the VX efficacy testing were attributed to solvent selection. Run 17 was repeated using the second solvent. The CCV problem was worse for this run, and the contact-hazard data was unusable.

11.12 Cross Contamination Blanks

Cross contamination during post-treatment handling can result from several factors. Vapor transfer may occur if the agent evaporates from one coupon and re-deposits (i.e., condenses) on another coupon. This could happen at any point, if the sample is not individually covered. Physical transfer of agent could occur by contact with contaminated forceps used to handle the coupons during any point of testing, such as transportation from Petri dishes into a test apparatus (e.g., extraction jar or vapor manifold).

Aluminum blank coupons were present in each container throughout testing. The blank coupons were analyzed for either contact or vapor tests. For HD, only one contact sample in a baseline run, and no vapor samples exhibited any cross contamination. For VX, several of the contact test blanks had cross contamination for baseline runs, and only one blank exhibited trace cross contamination for vapor samples in an efficacy run.

GD has significantly higher vapor pressure than the other agents studied, thus vapor transfer is of larger concern. Using the blanks, GD was identified in vapor-transfer cross contamination during transport from the decontamination chamber to the test facility. After the first few runs, the coupons were individually covered to prevent this type of cross contamination. Both TGD and GD exhibited some amount of cross contamination, all of which were less than 0.8 JPID contact objective ORD factors after the coupons were individually covered. Cross contamination was more significant for the 10 g/m^2 than for the 1 g/m^2 starting challenge.

Blank

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ACRONYMS

APG	Aberdeen Proving Grounds
BW	Biological Warfare
BI	Biological Indicator
BSL-3	Biosafety Level Three
CAPO	Capability Area Project Officer
CARC	Chemical Agent Resistant Coating
CASARM	Chemical Agent Standard Reference Material
CB	Chemical and Biological
CCV	Continuing Calibration Verification
CI	Chemical Indicator
CoC	Chain of Custody
CofA	Certificate of Analysis
CRADA	Coperative Research and Development Agreement
CT	Concentration Time (units: ppm h)
CW	Chemical Warfare
DAAMS	Depot Area Air Monitoring System
DoD	Department of Defense
DPG	Dugway Proving Ground
DS	Decontamination Sciences
DTRA	Defense Threat Reduction Agency
ECBC	Edgewood Chemical Biological Center
Exp.	Exposure (time)
Ext. Eff.	Extraction Efficiency
FPD	Flame Photometric Detector
GC	Gas Chromatography
GC-MS	Gas Chromatography-Mass Spectroscopy
GD	Soman, non-persistent agent
HD	Distilled mustard agent
H_2O_2	Hydrogen Peroxide
IAW	In Accordance With
ICV	Initial Calibration Verification
IOP	Internal Operating Procedure
JMDS	Joint Material Decontamination System
JPID	Joint Platform Interior Decontamination
JPM	Joint Program Management
JSID	Joint Service Interior Decontamination
JSSED	Joint Service Sensitive Equipment Decontamination
KPP	Key Performance Parameter
LOE	Limited Objective Experiment
MDL	Method Detection Limit
MSD	Mass Selective Detector
MSDS	Material Safety Data Sheets
NH3	Ammonia
NMR	Nuclear Magnetic Resonance
ORD	Operational Requirements Document
PEL	Permissible Exposure Level
pFPD	pulsed Flame Photometric Detector

PI	Principal Investigator
PM	Project Management
PPE	Personal Protective Equipment
Pre-Op	Pre-Operational
R&D	Research and Development
RDECOM	Research, Development, and Engineering Command (formerly SBCCOM)
RH	Relative Humidity
RPD	Relative Percent Deviation
RRO	Risk Reduction Office
SBCCOM	Soldier and Biological Chemical Command
SCBA	Self-Contained Breathing Apparatus
SD	Standard Deviation
SED	Sensitive Equipment Decontamination
SOPs	Standing (Standard) Operating Procedures
SOR	Start of Run
STE	Strategic Technology Enterprises
STEL	Short Term Exposure Level
TDG	Thiodiglycol
TDS	Thermal Desorption System
TGD	Thickened GD
TOP	Test Operating Procedure
TWA	Time-Weighted Average
VHP®, VHP	STERIS' registered "vaporized hydrogen peroxide" procedure
VX	Methylphophonothioic acid, persistent nerve agent

APPENDIX A
COUPON STOCK MATERIAL AND PREPARATION

Glass
Type: Heat-Resistant Borosilicate Glass
Supplier: McMaster-Carr, part # 8477K12
Stock Material: individual 2 in. diameter x 0.125 in. Thick, heat-resistant, borosilicate sight glasses
Preparation Details:
Chemical surrogate Tests: 2 in. disks (sight glasses) purchased directly from supplier, used as supplied.

Aluminum
Type: 5052
Supplier: E-J Enterprises
Stock Material: received as 48 in.x 120 in.sheets, 0.125 in.thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop, washed with soapy water to remove processing oils, rinsed with distilled water, and air dried.

Chemical Agent Resistant Coating (CARC)-painted Aluminum
Type: Aluminum 5052, painted with Forest Green CARC, MIL-C-53039A
Supplier: E-J Enterprises
Stock Material: received as 48 in.x 120 in.sheets, 0.125 in.thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop, then painted on one face plus edges with Chemical Agent Resistant Coating, MIL-C-53039A, according to established procedures.

Polycarbonate (Decon Sciences Samples)
Type: Clear Polycarbonate Sheet
Supplier: E-J Enterprises, order # 0001-03460
Stock Material: received as 48 in.x 96 in.sheets, 0.22 in.thick
Preparation Details:
Chemical surrogate tests: 2 in. disks cut at ECBC Fabrication shop. Initial coupons were cut out using a water jet; later coupons were cut using a 2 in. diameter die. Coupons were then washed with warm, soapy water, rinsed with distilled water, and allowed to air dry.

Polycarbonate (JSSED Program Provided Samples)
Type: Clear Polycarbonate Sheet
Supplier: E-J Enterprises, order # 0001-03460
Stock Material: received as 48 in.x 96 in.sheets, 0.22 in.thick
Preparation Details:
Chemical surrogate tests: Coupons were washed with warm, soapy water, rinsed with distilled water, and allowed to air dry.

U.S. Air Force Topcoat Painted Aluminum

Type: Aluminum 5052, painted with Grey USAF Topcoat, MILK-PRF-85285
Supplier: E-J Enterprises, order #
Stock Material: received as 48 in.x 120 in.sheets, 0.125 in.thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop, then painted on one face plus edges with US Air Force Topcoat, MILK-PRF-85285.

Silicone Elastomer

Type: Silicone Elastomer - Sheet MQ/VNQ/PMQ/PVMQ
Supplier: Goodfellow, Order #089-628-36
Stock Material: received as 500 mm x 500 mm sheets, 3.0 mm thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop, washed with soapy water to remove processing oils and dirt, rinsed with distilled water, and air dried.

Kapton®

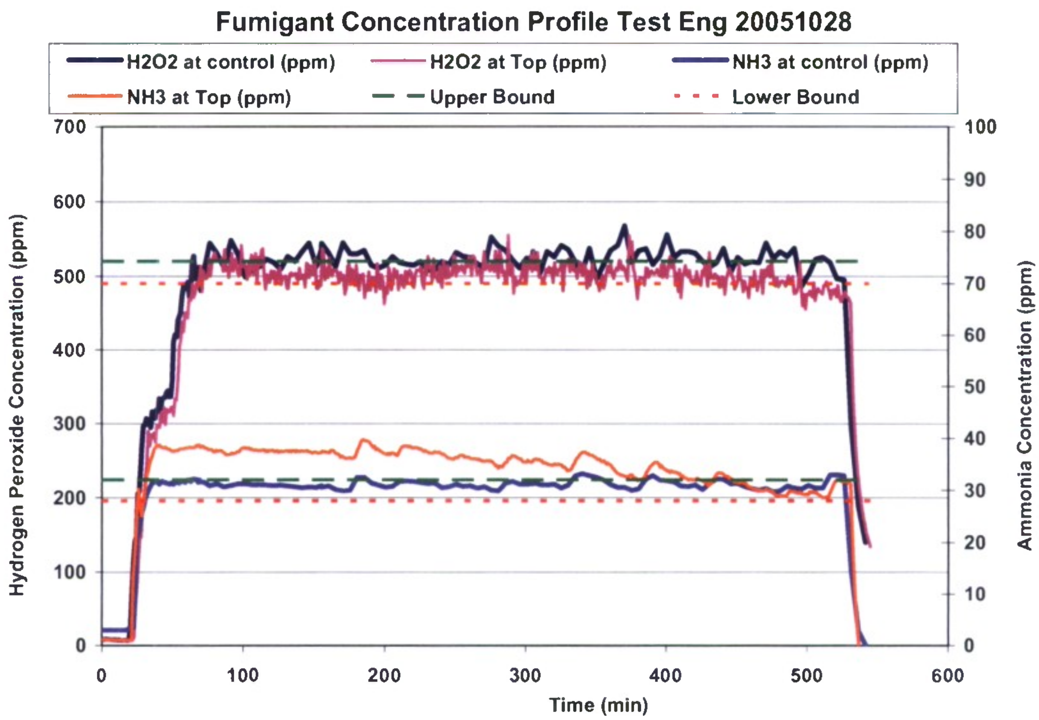
Type: Polyimide (PI) Film, grade Kapton HN
Supplier: Goodfellow, order # LS257291
Stock Material: received as 610 mm x 2 m coil, 0.125 mm thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop.

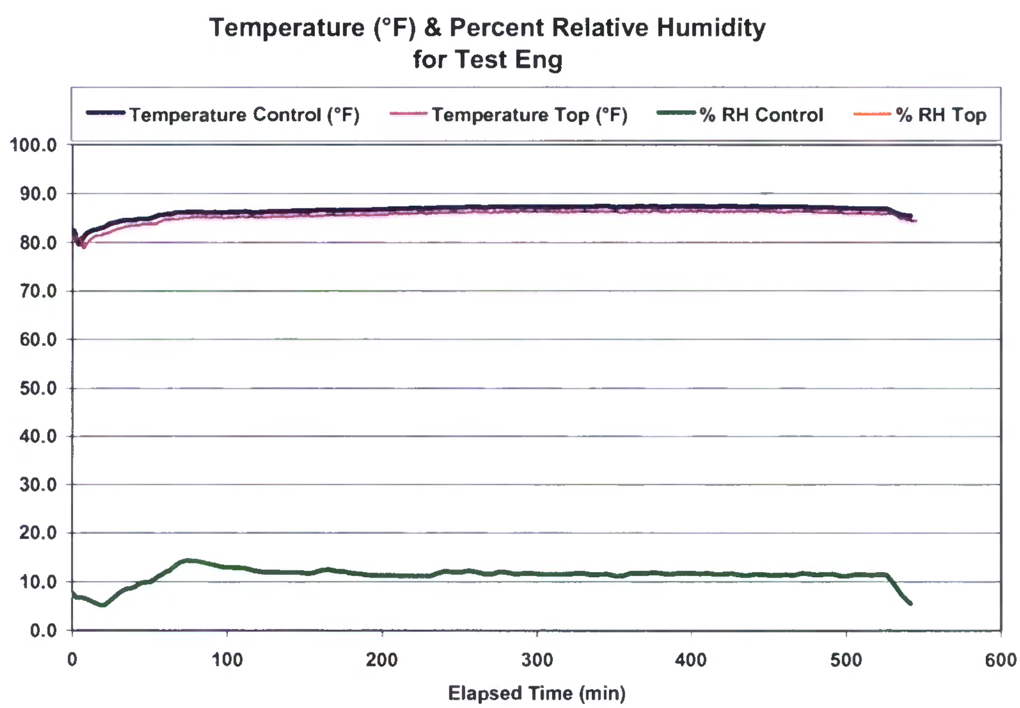
Viton® (Gasket Material, n-nitrile)

Type: Hexafluoropropylene-vinylidene fluoride copolymer sheet FKM
Supplier: Goodfellow, order # FV313300
Stock Material: received as 300 mm x 300 mm sheets, 3.0 mm thick
Preparation Details:
Chemical surrogate tests: 2 in. disks punched at ECBC Fabrication shop.

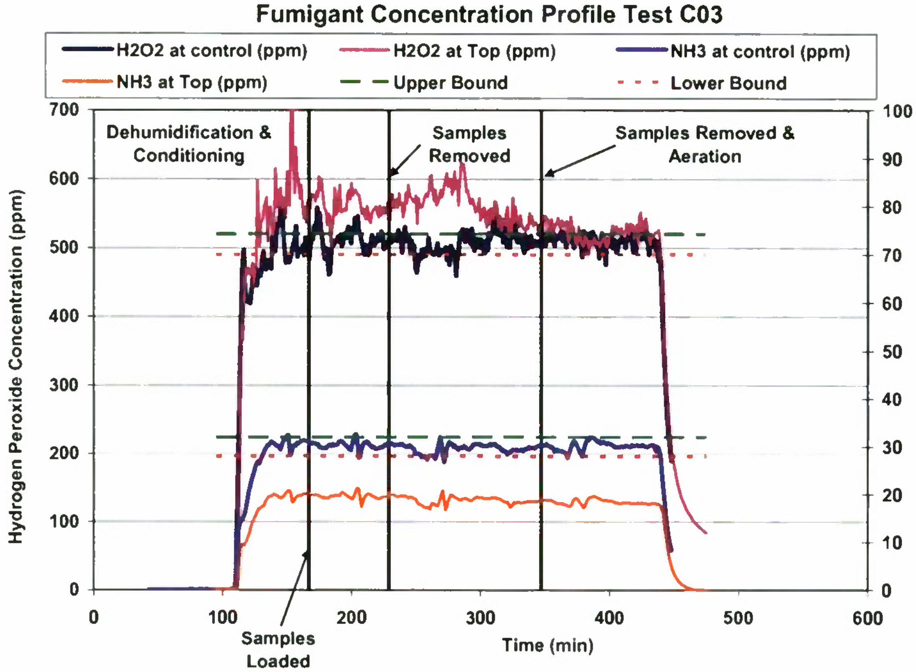
APPENDIX B
CONTROL CHARTS

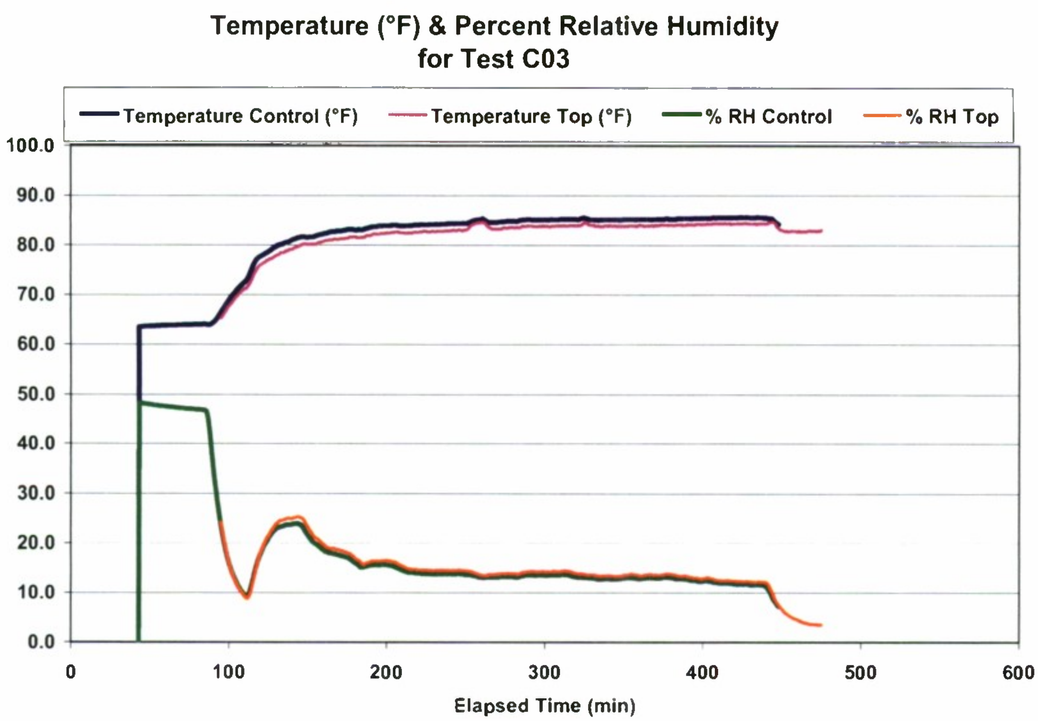
B.1 Engineering Test (Run 0): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





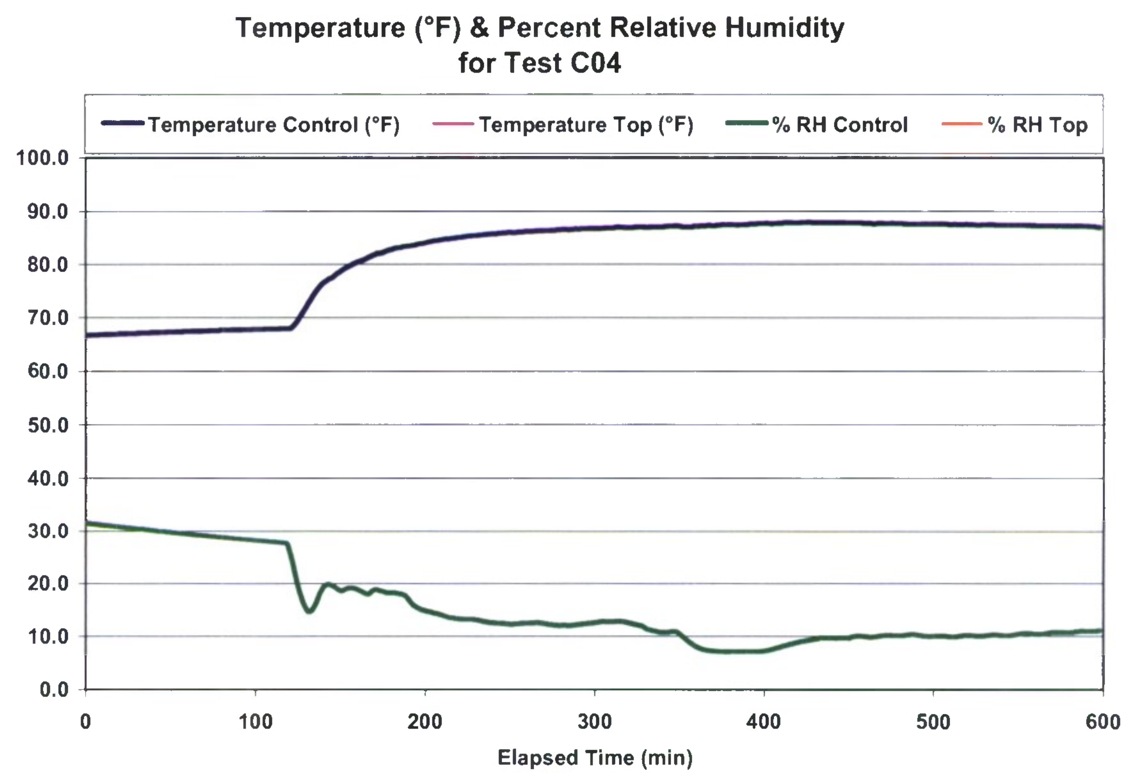
B.2 GD Scoping Test (Run 3): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



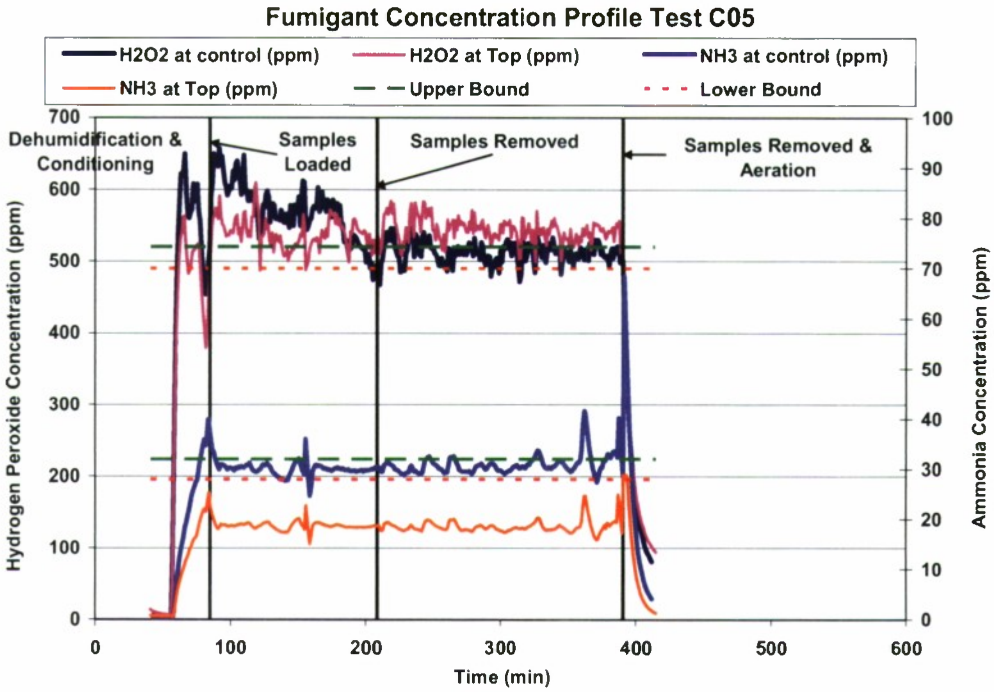


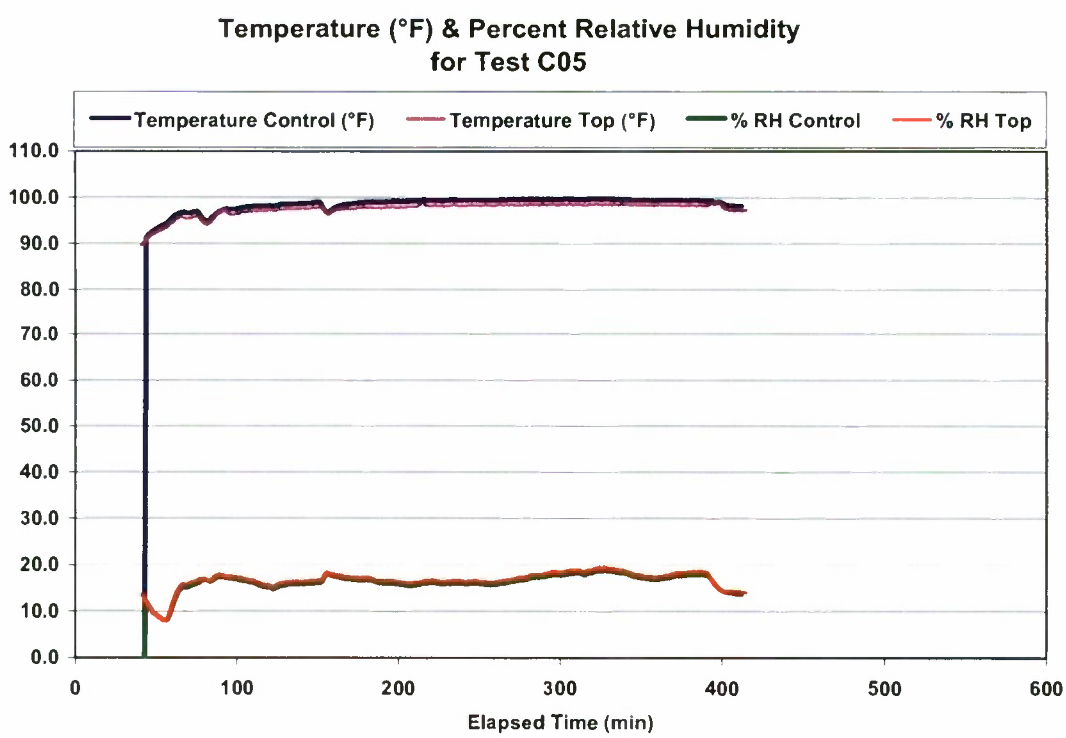
B.3 GD Baseline Test (Run 4): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.



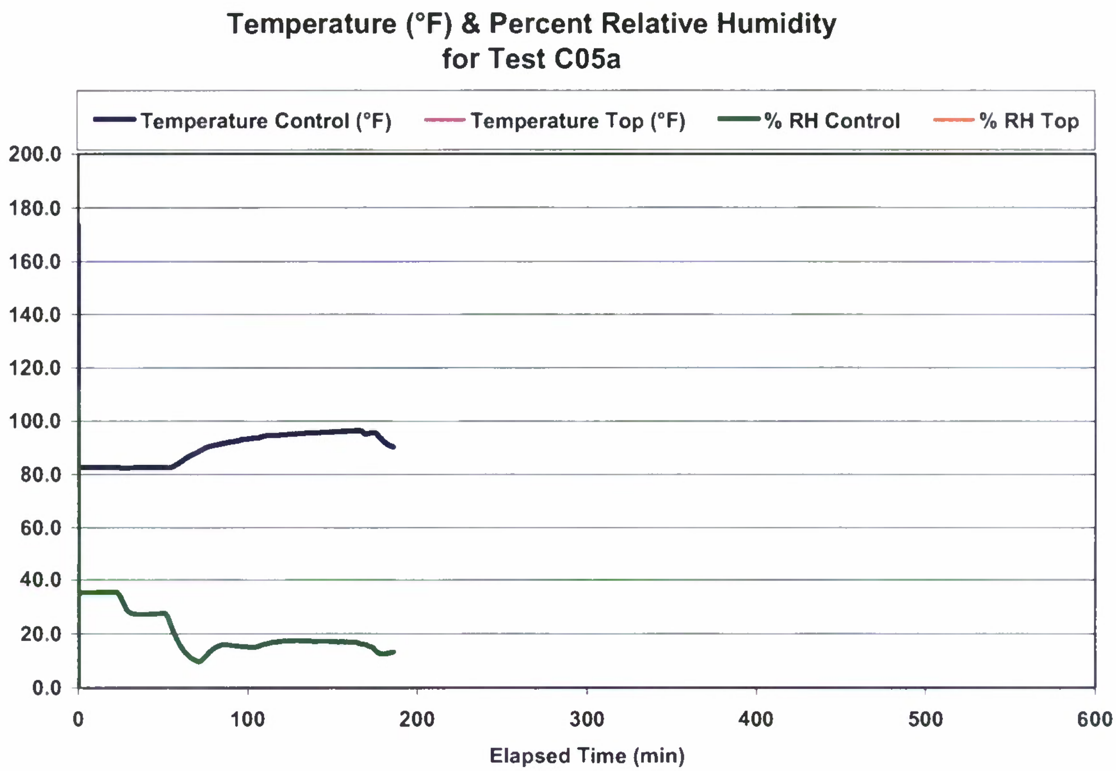
B.4 GD Efficacy A Test (Run 5): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



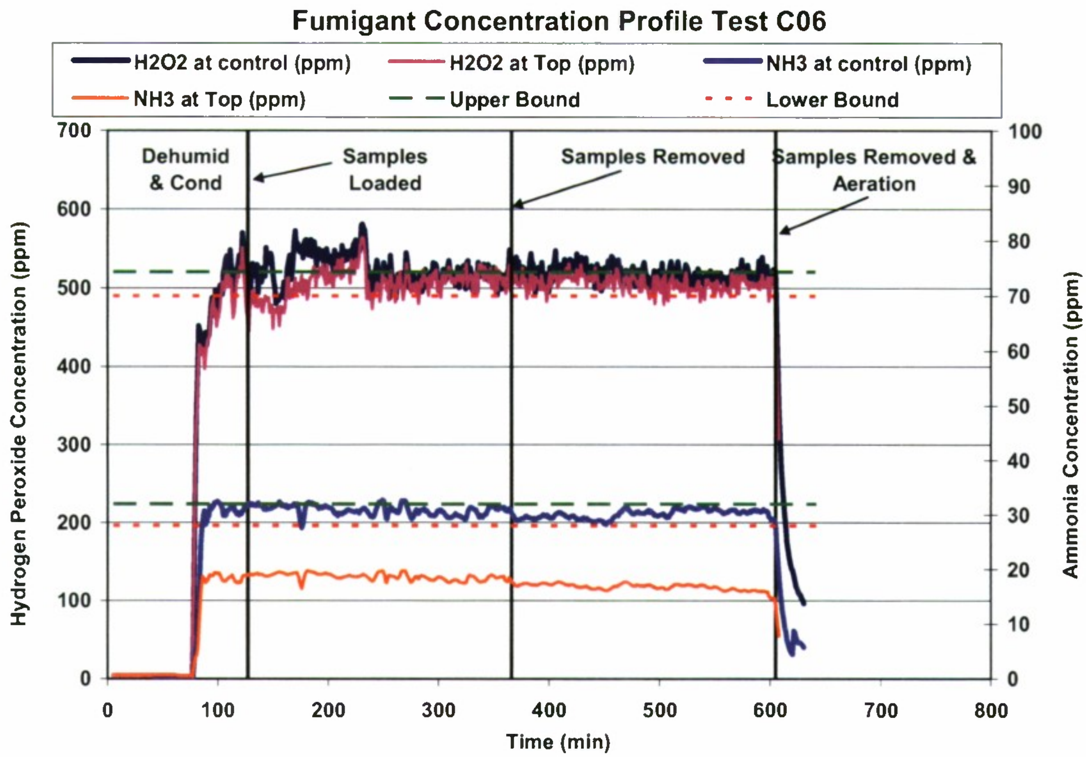


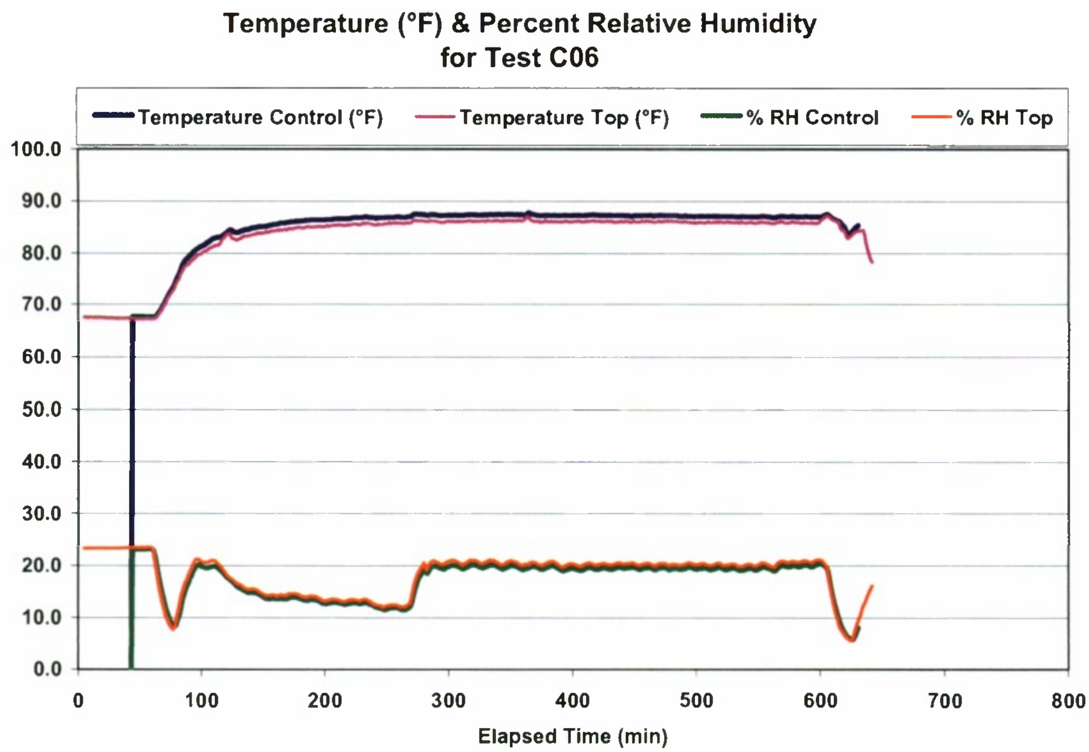
B.5 GD Baseline Test (Run 5a): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.

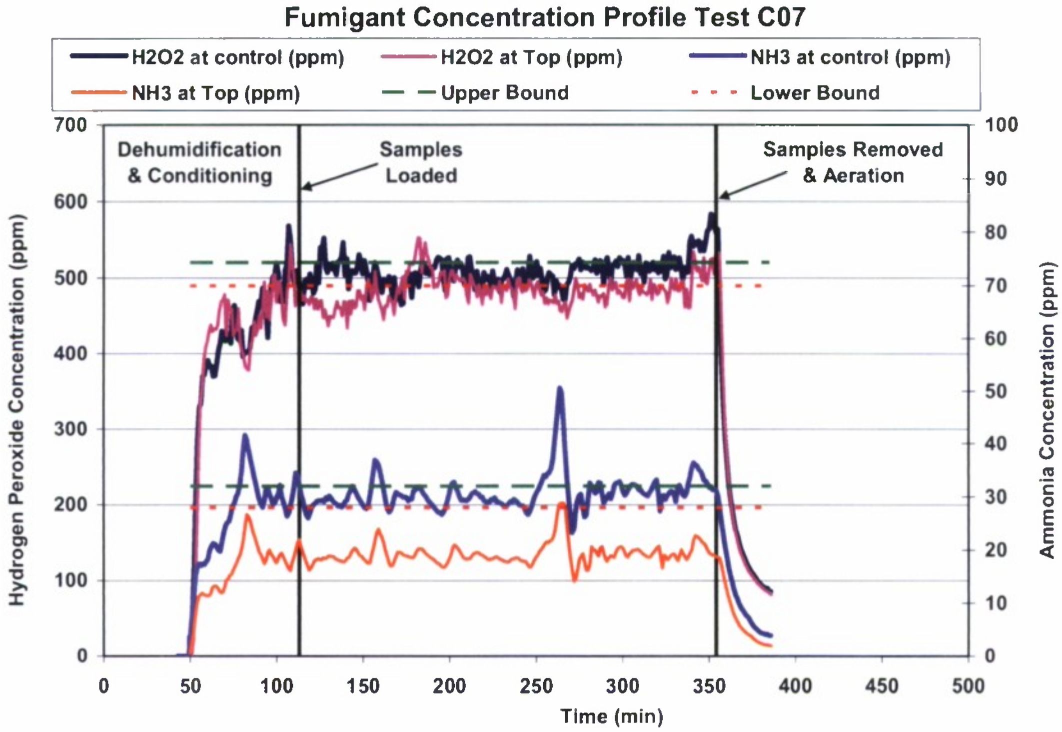


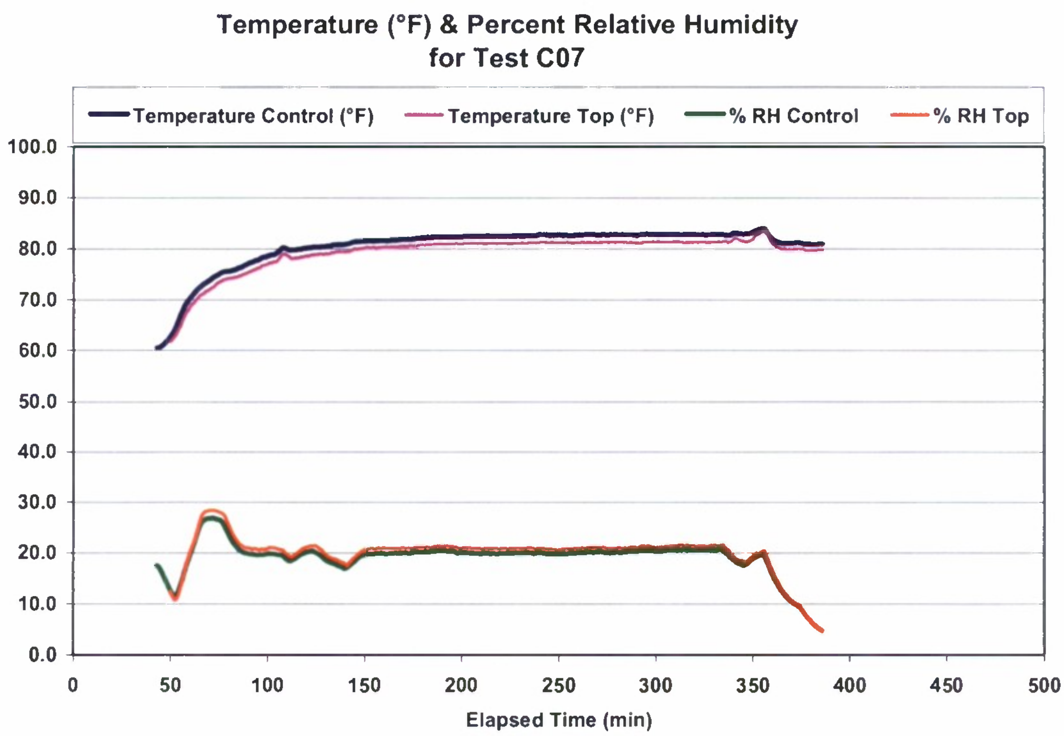
B.6 GD Efficacy B Test (Run 6): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





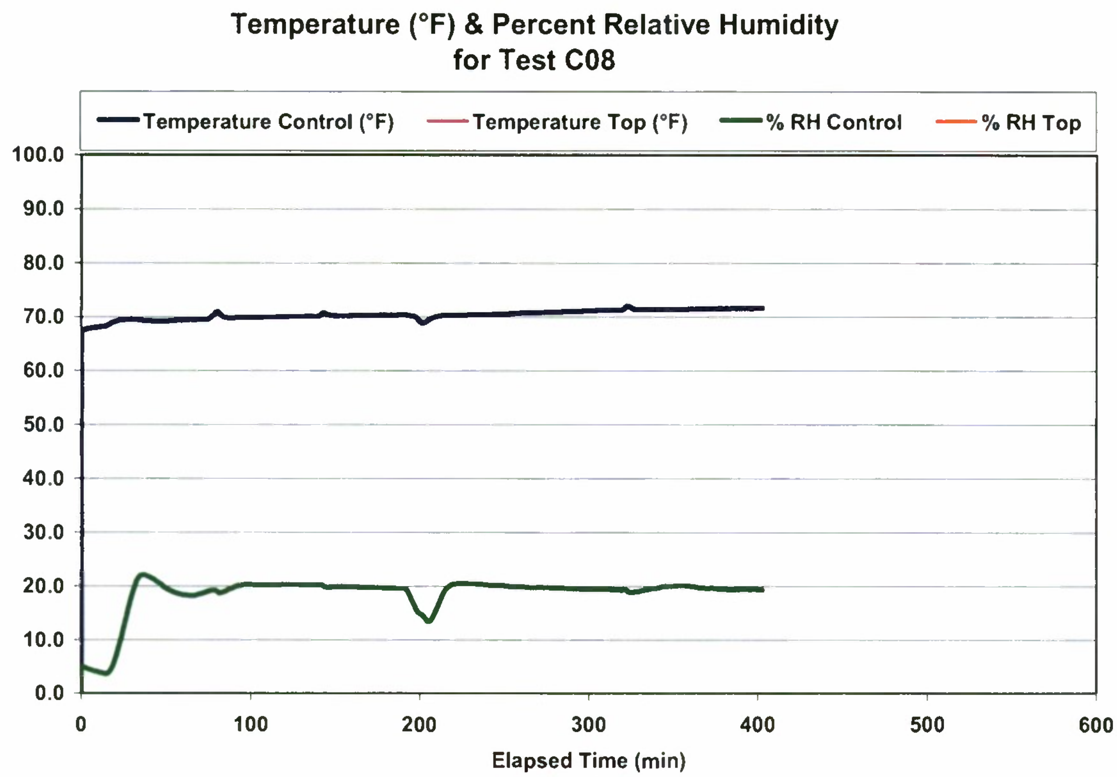
B.7 TGD Scoping Test (Run 7): Fumigant Concentration, and Temperature and Relative Humidity Process Control Chart



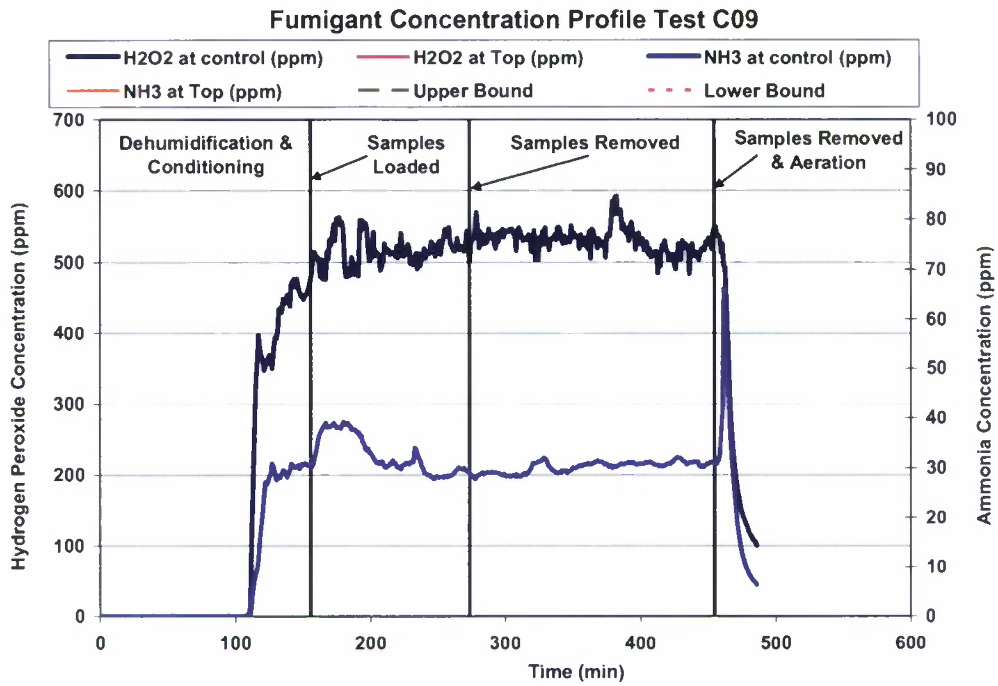


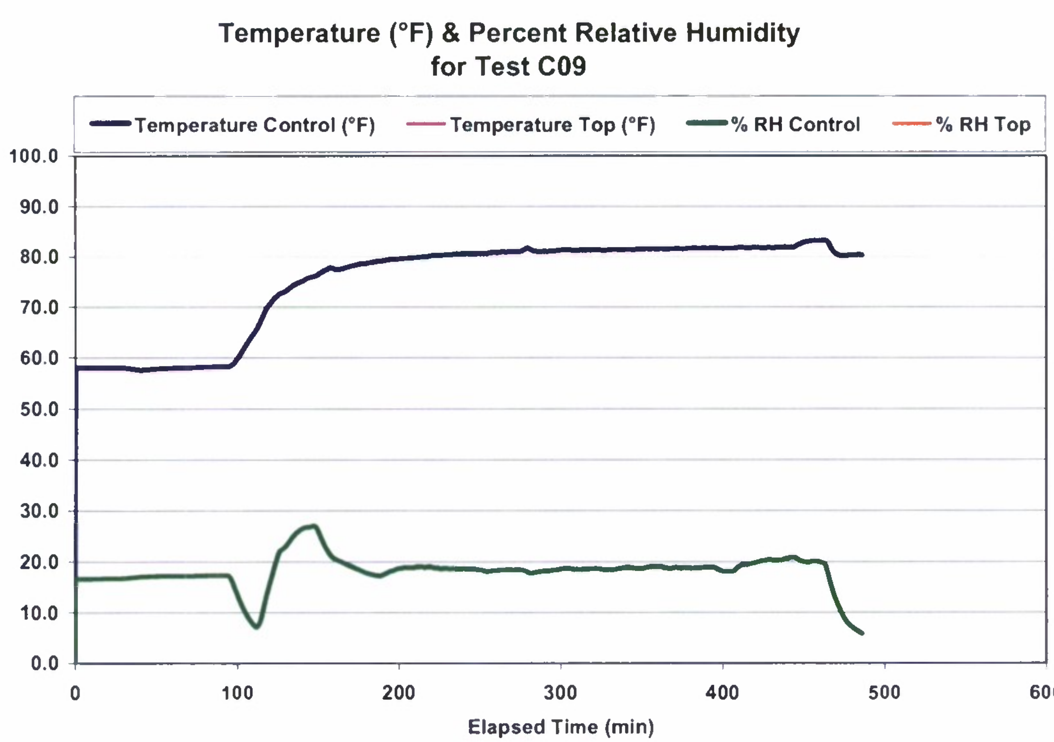
B.8 TGD Baseline Test (Run 8): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.

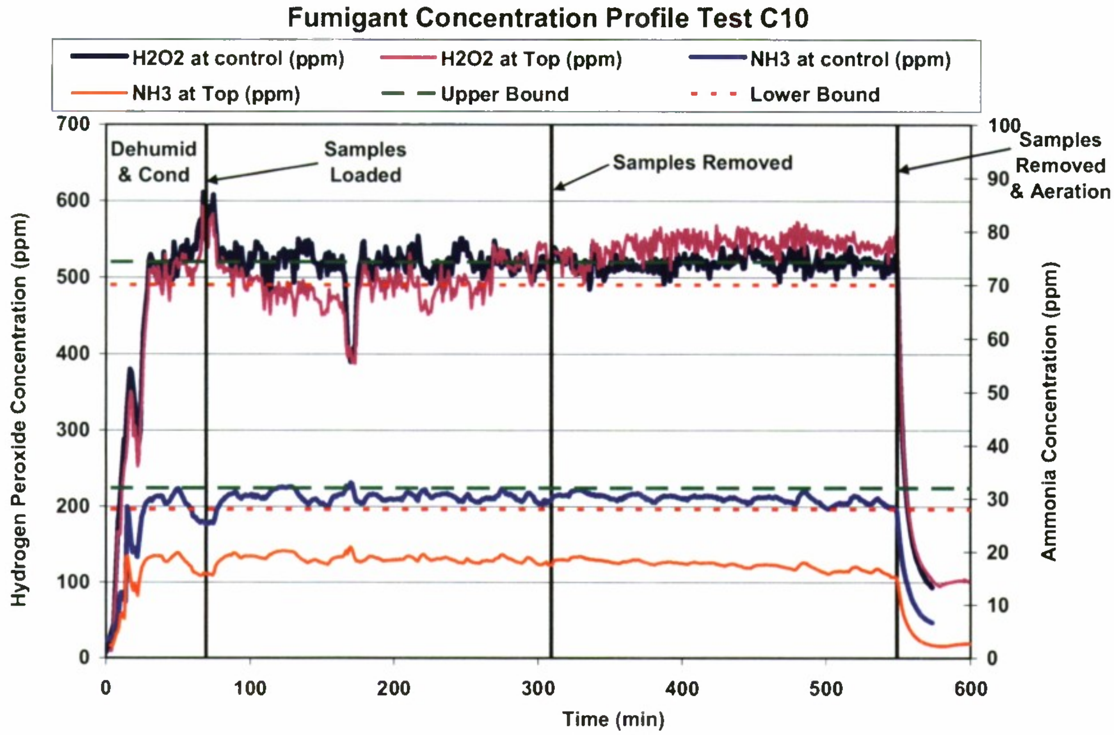


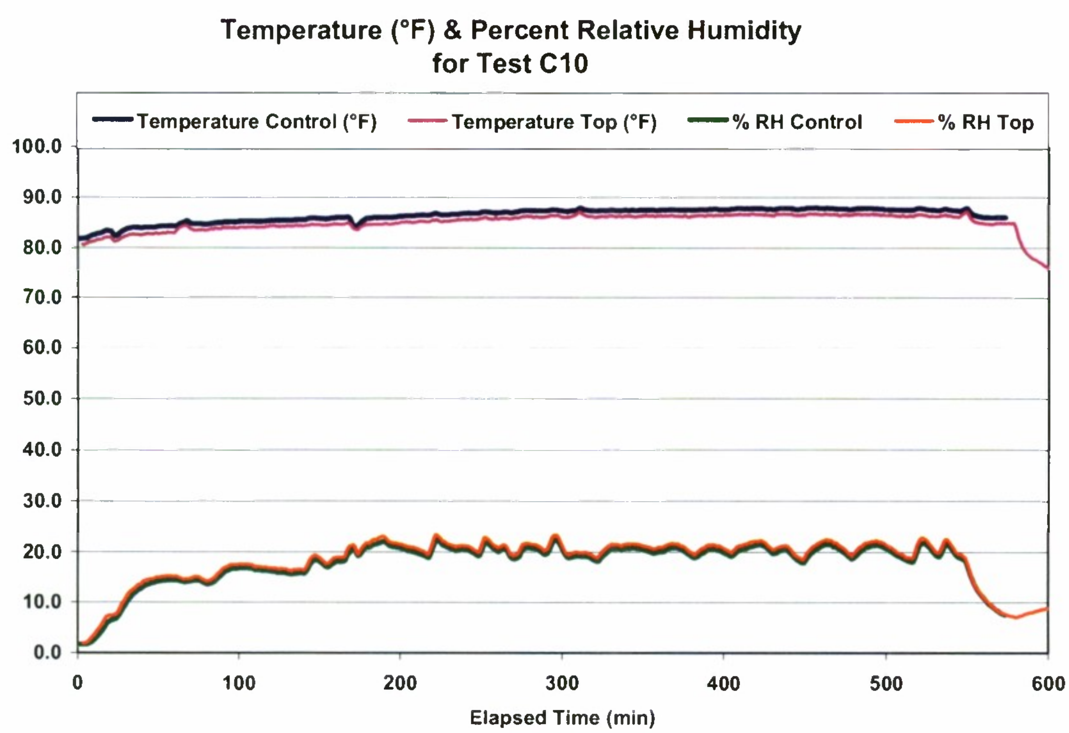
B.9 TGD Efficacy A Test (Run 9): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



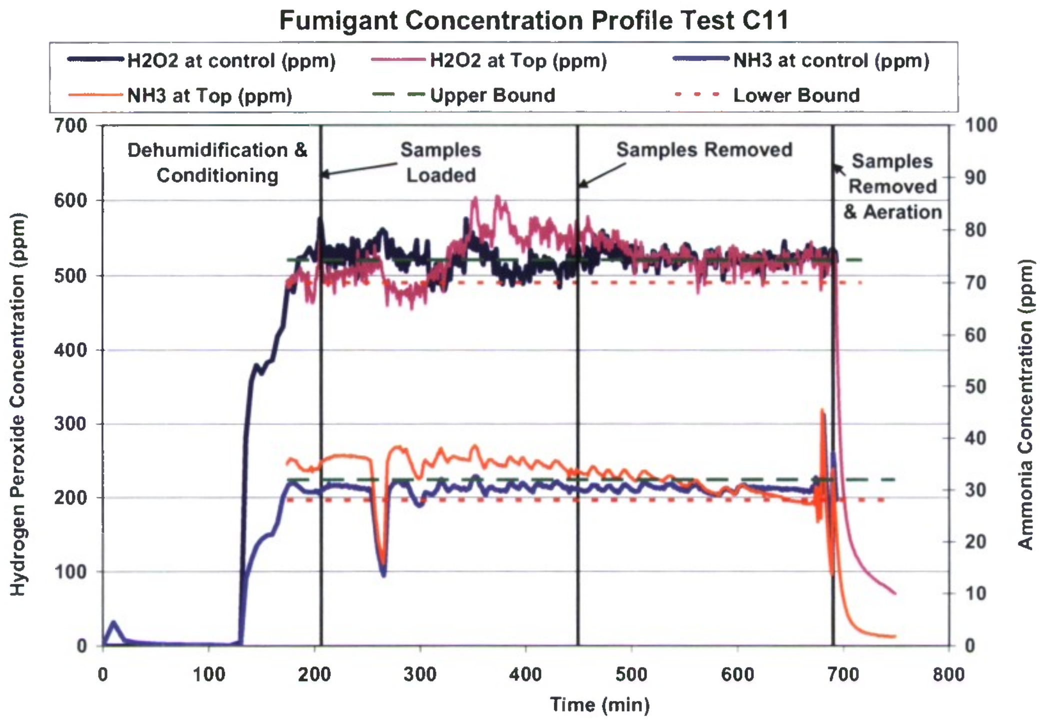


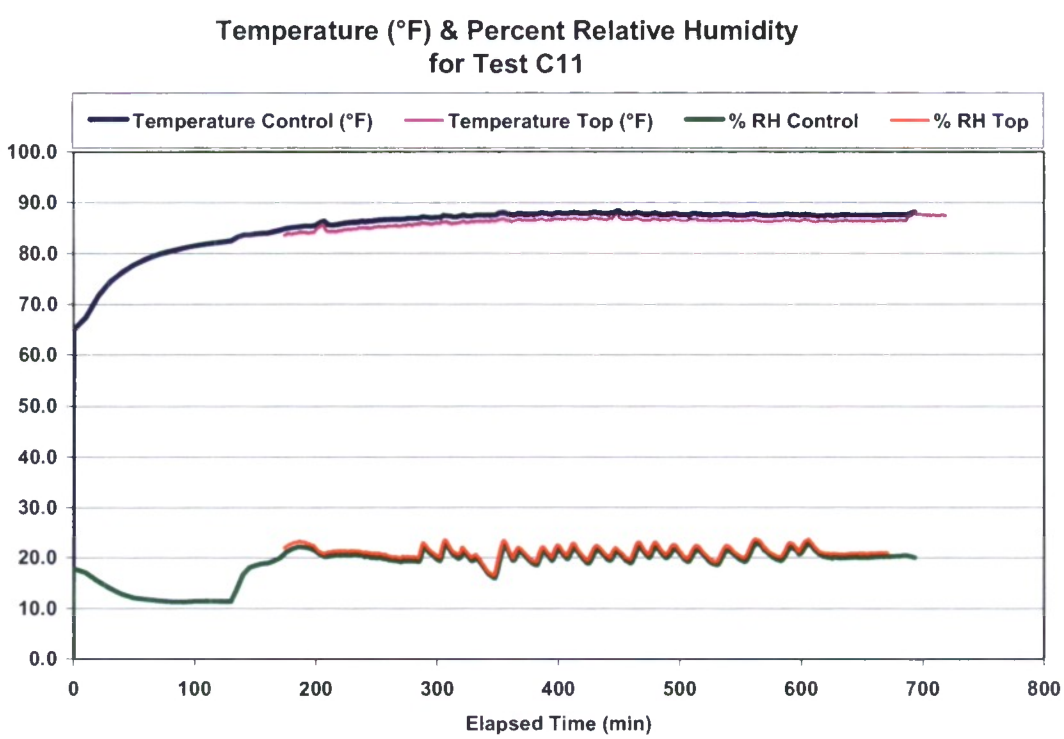
B.10 TGD Efficacy B Test (Run 10): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



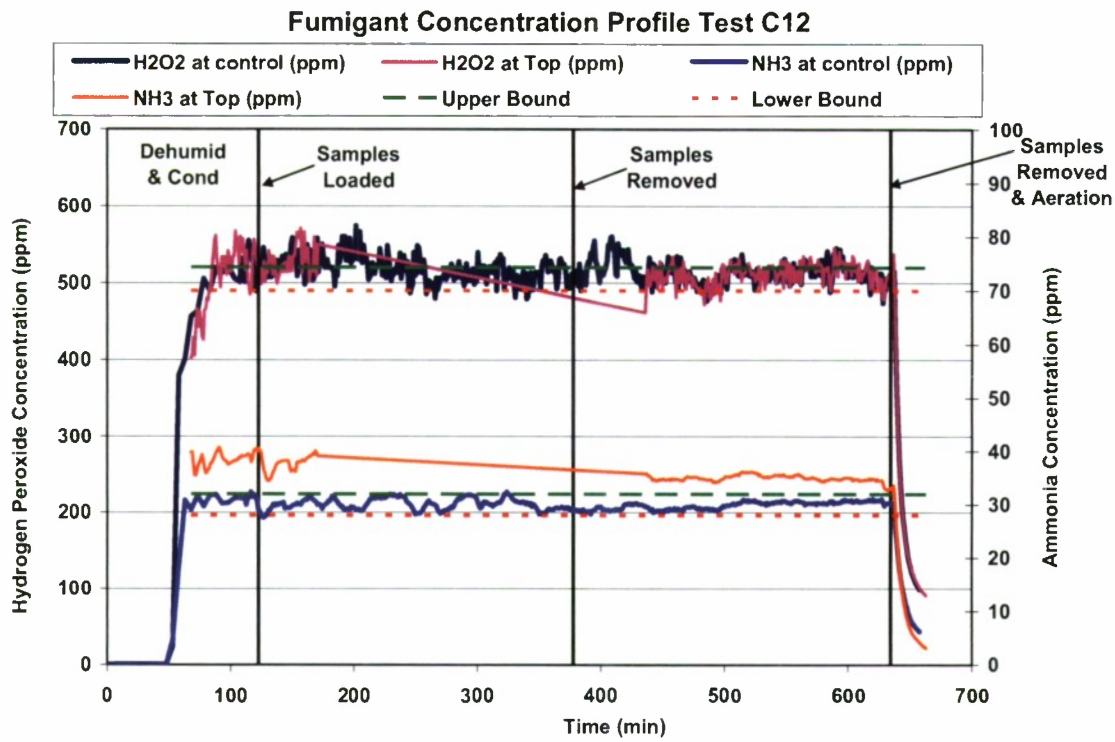


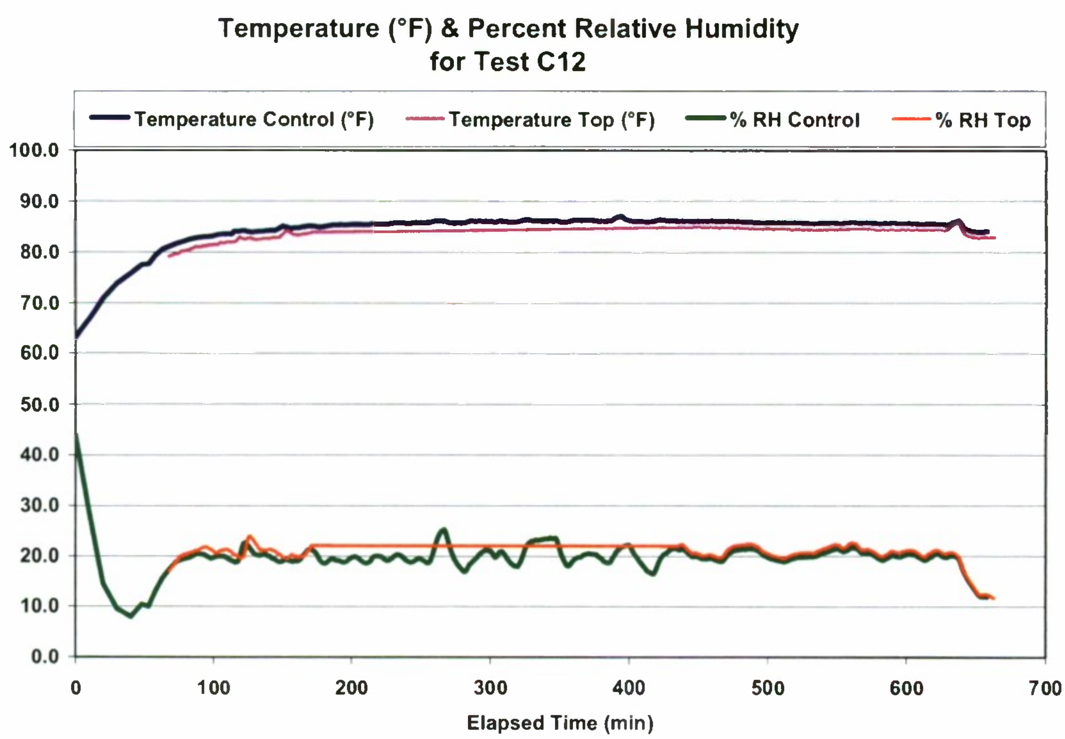
B.11 TGD Scoping Test 2 (Run 11) : Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



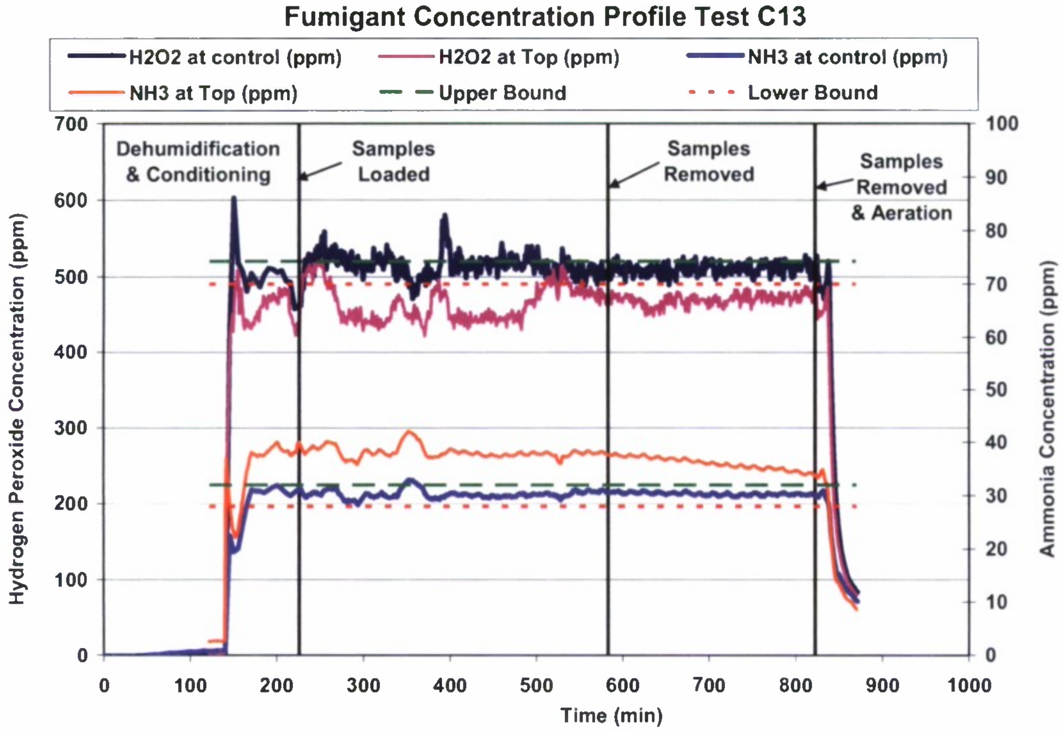


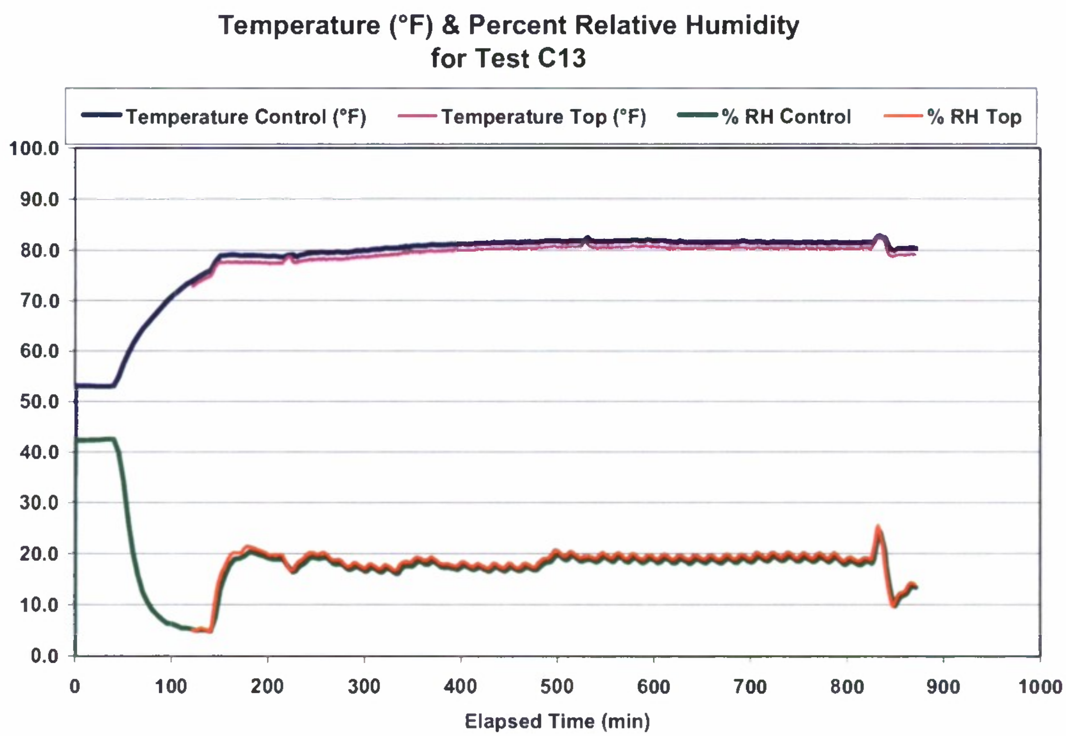
B.12 TGD Efficacy A Wipe Test (Run 12): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



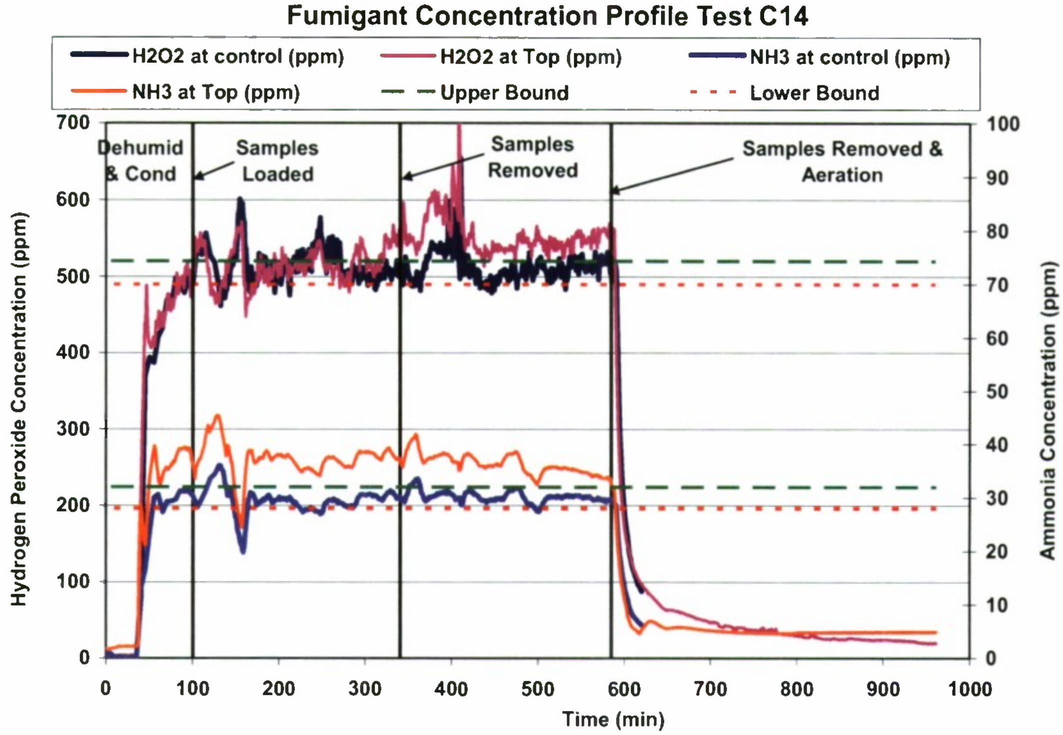


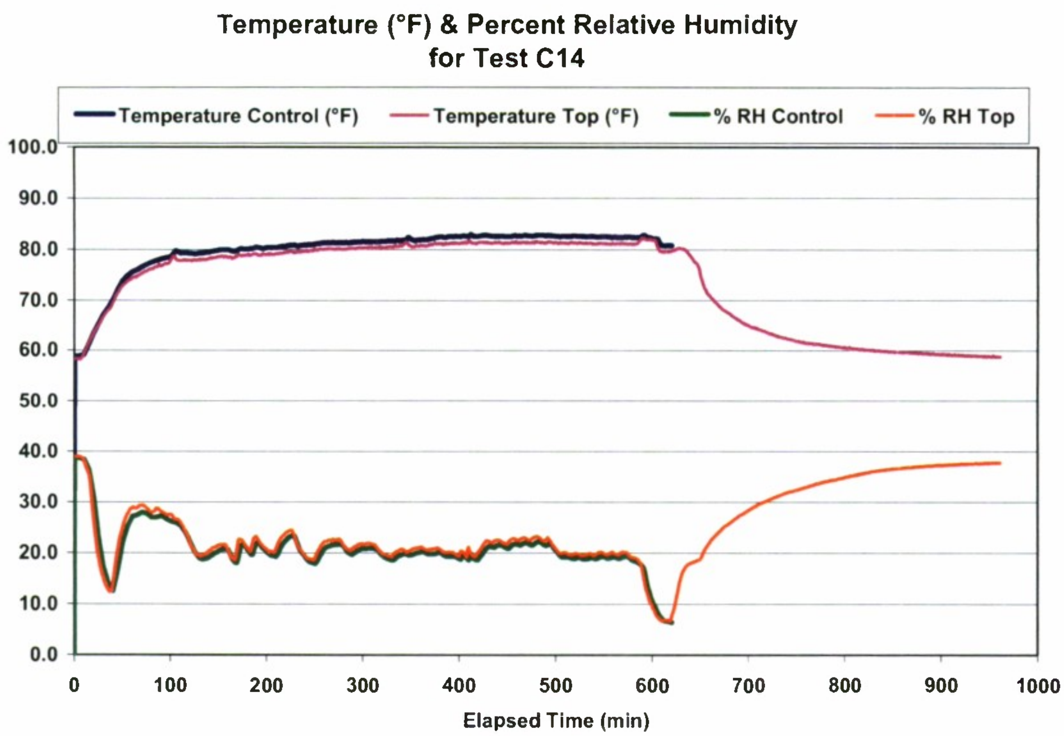
B.13 TGD Efficacy B Wipe Test (Run 13): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





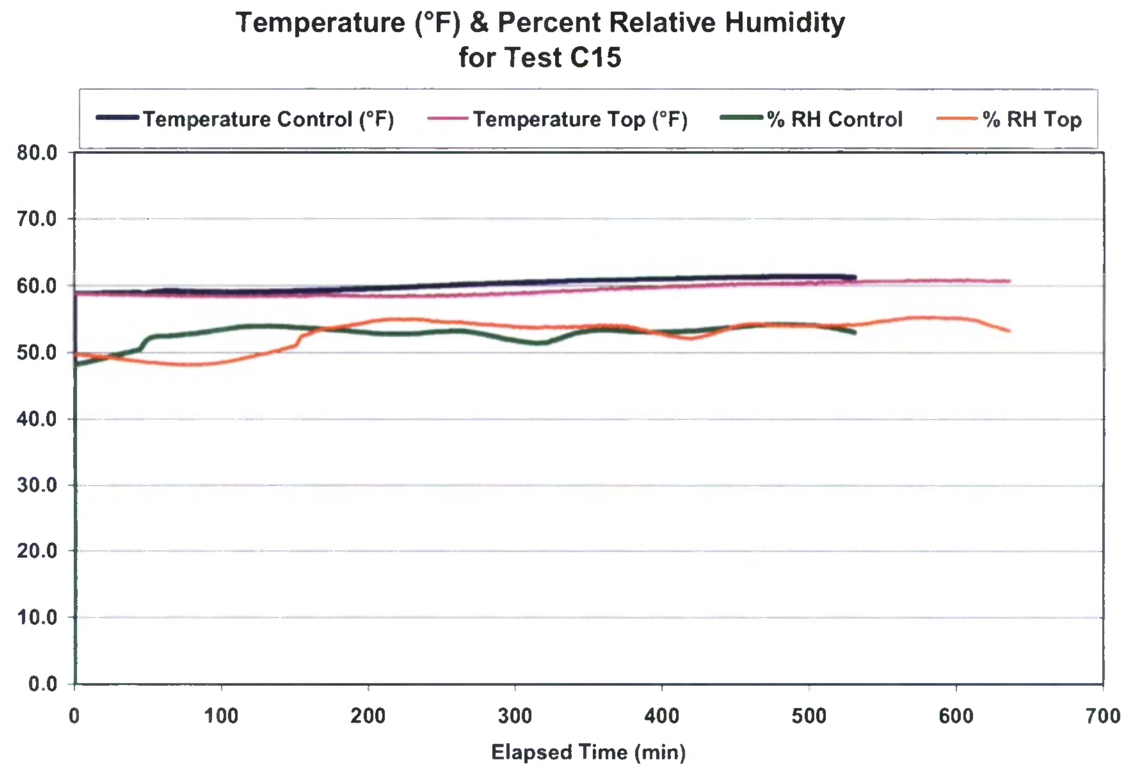
B.14 VX Scoping Test (Run 14): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



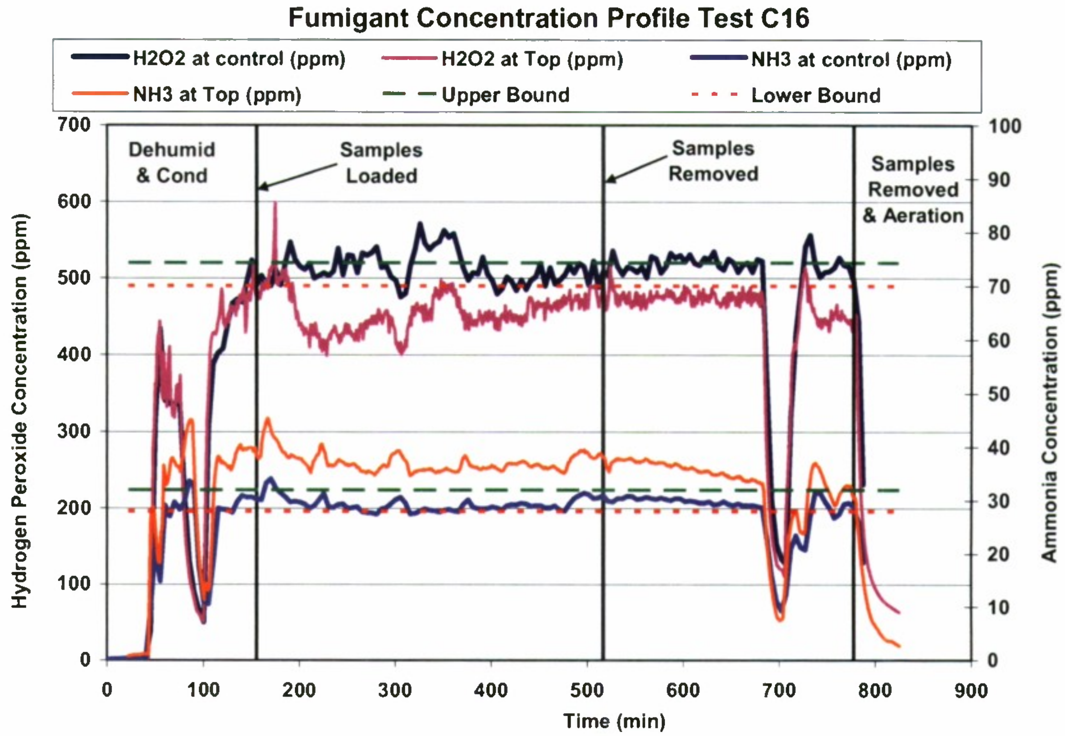


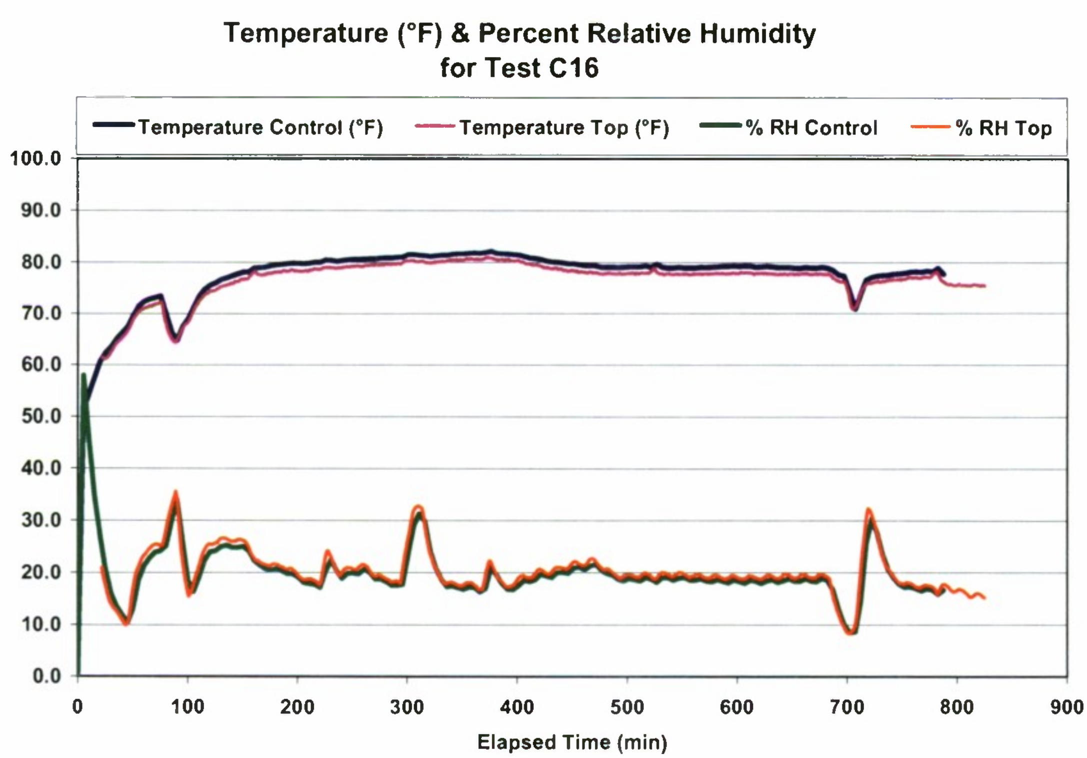
B.15 VX Baseline Test (Run 15): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.

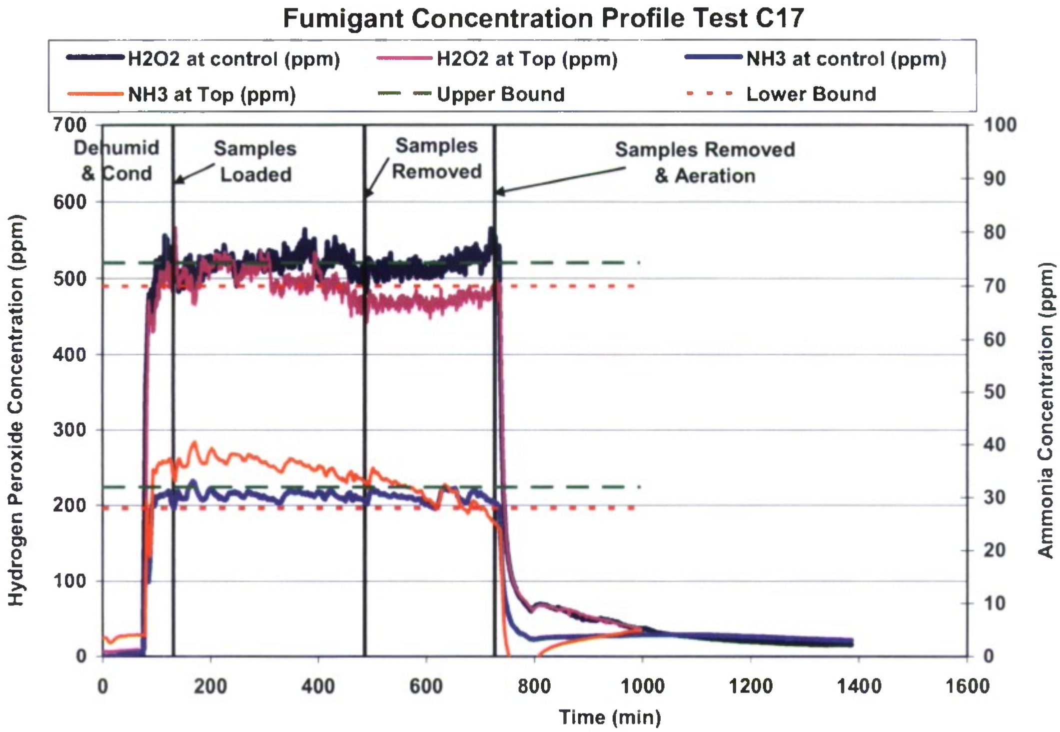


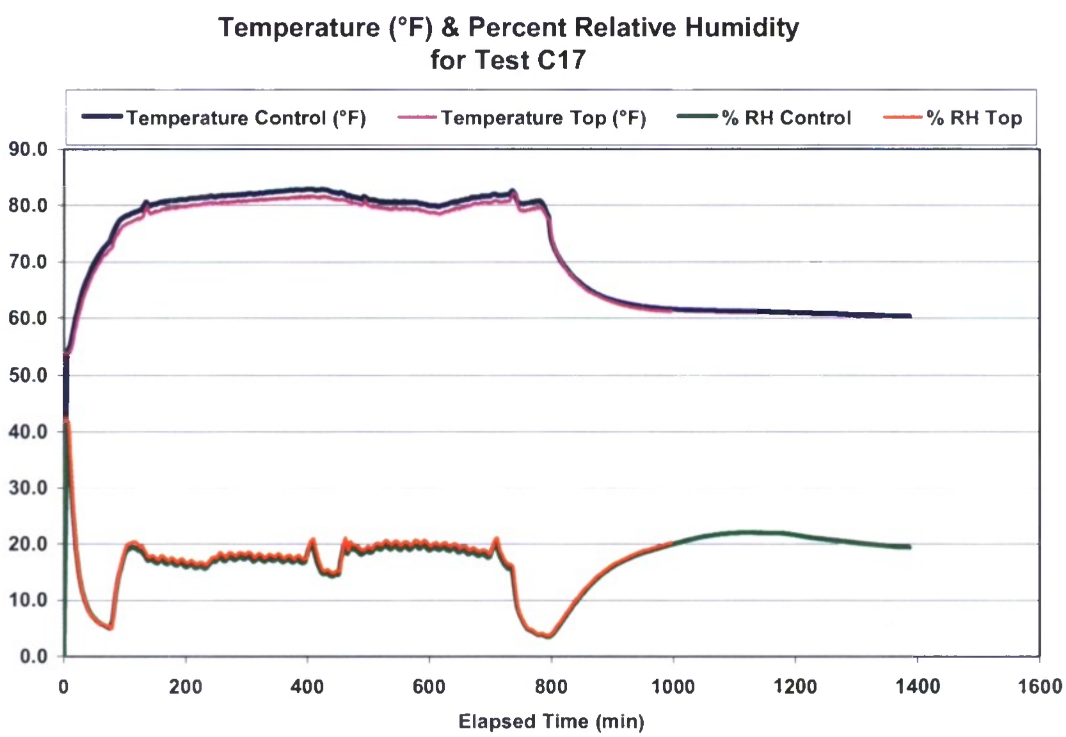
B.16 VX Efficacy A Test (Run 16): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



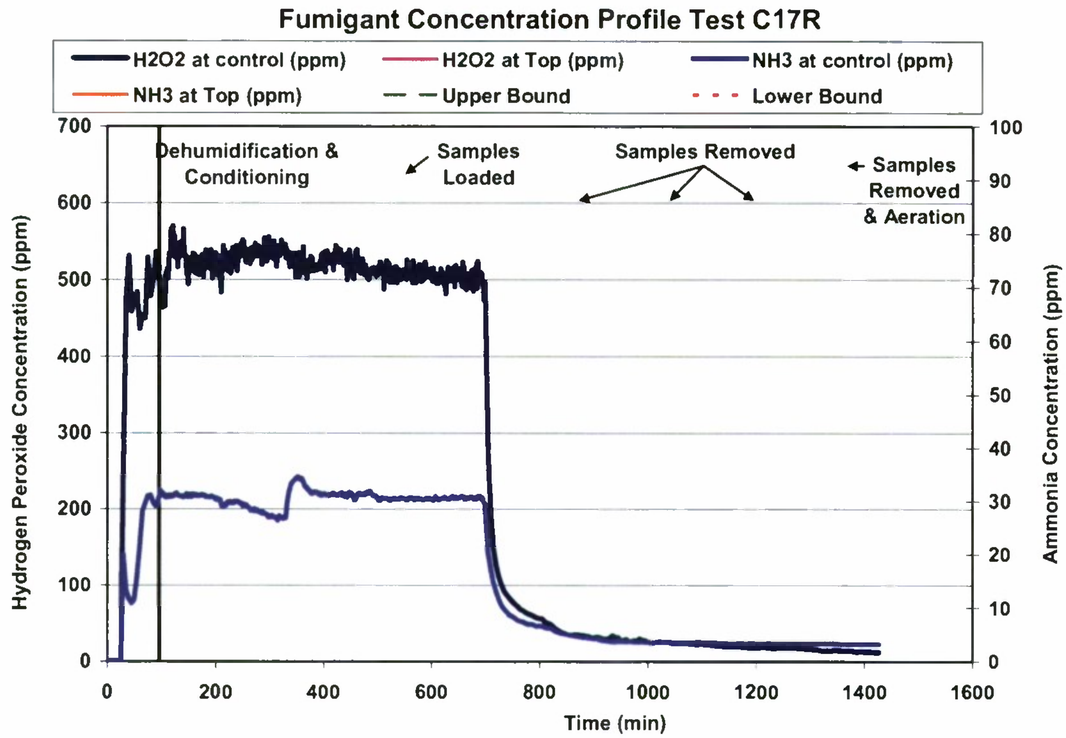


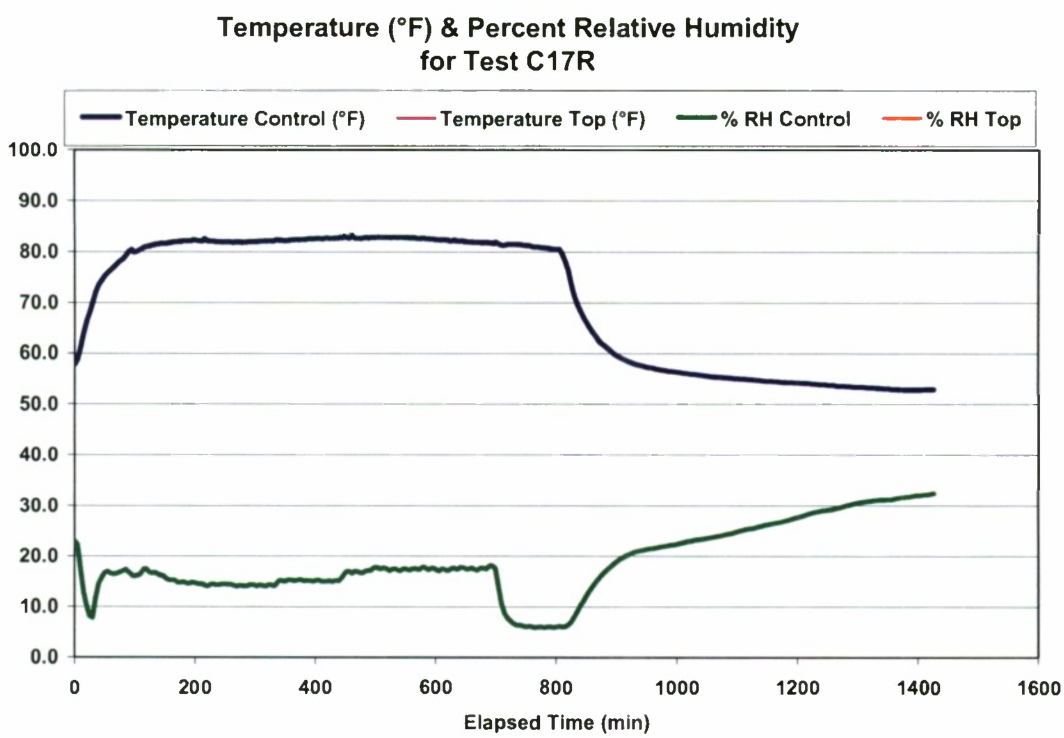
B.17 VX Efficacy B Test (Run 17): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



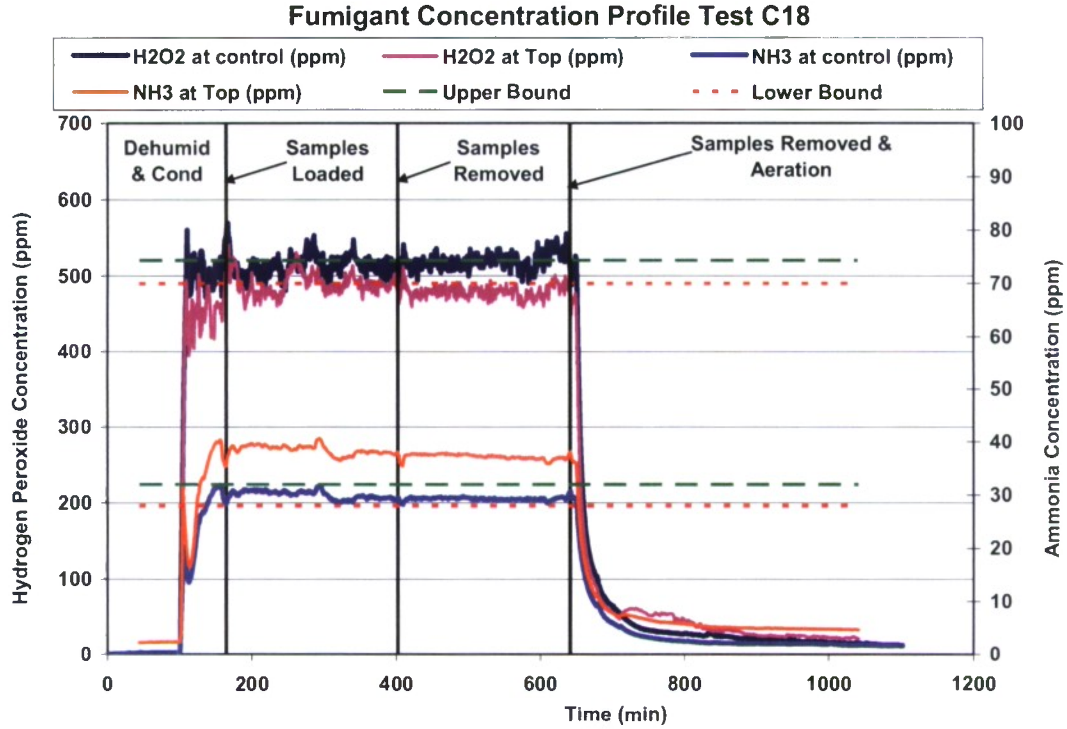


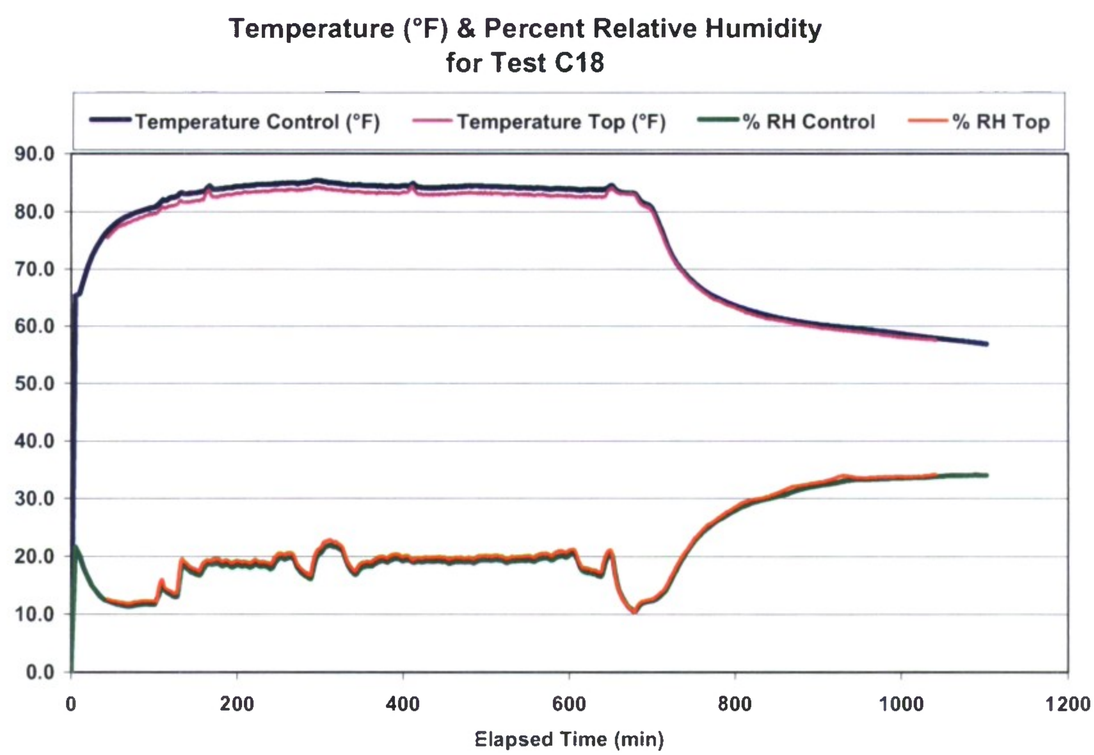
B.18 VX Efficacy Repeat Test (Run 17R): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





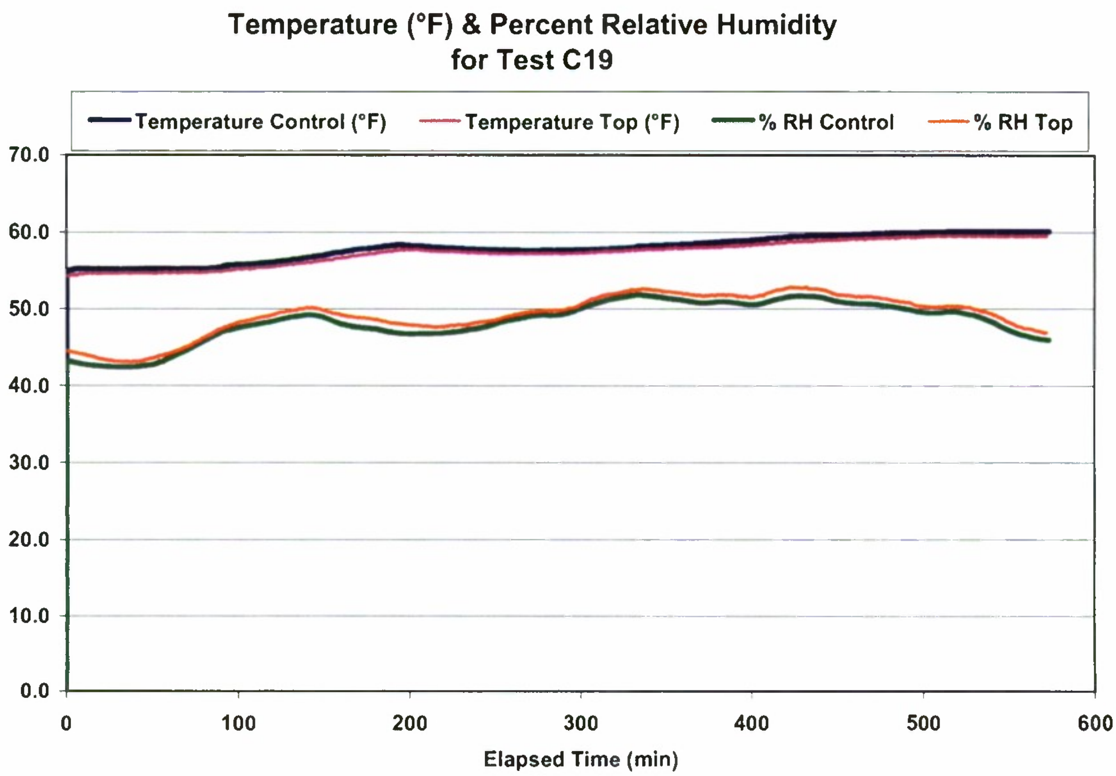
B.19 HD Scoping Test (Run 18): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



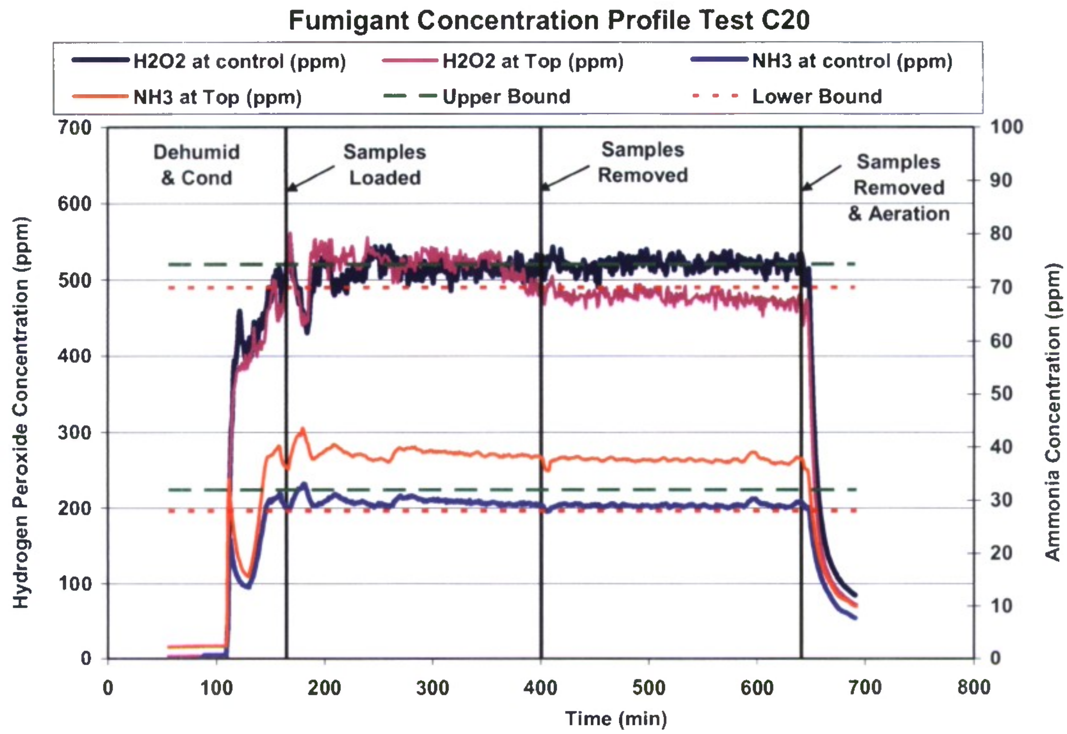


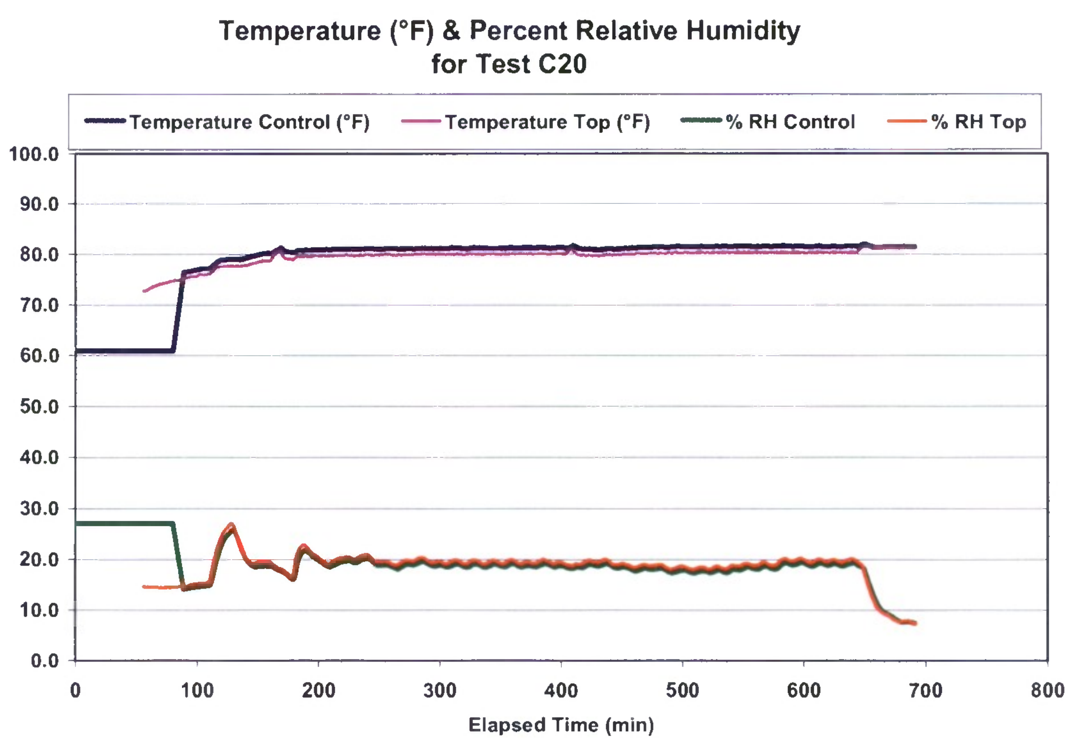
B.20 HD Baseline Test (Run 19): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.

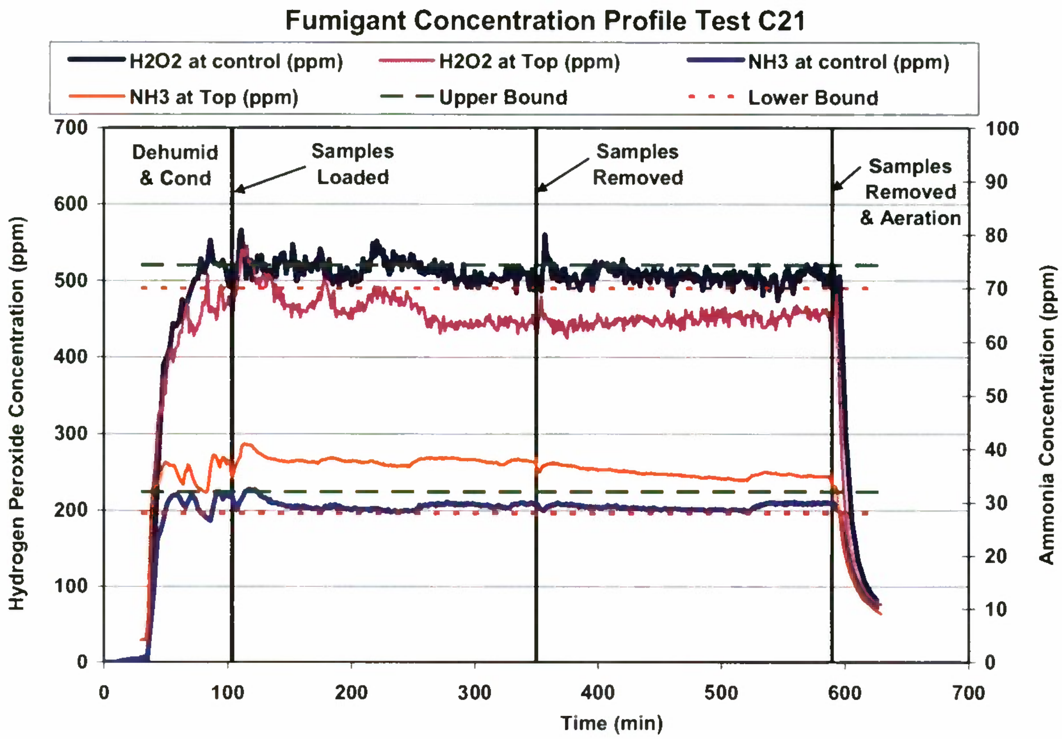


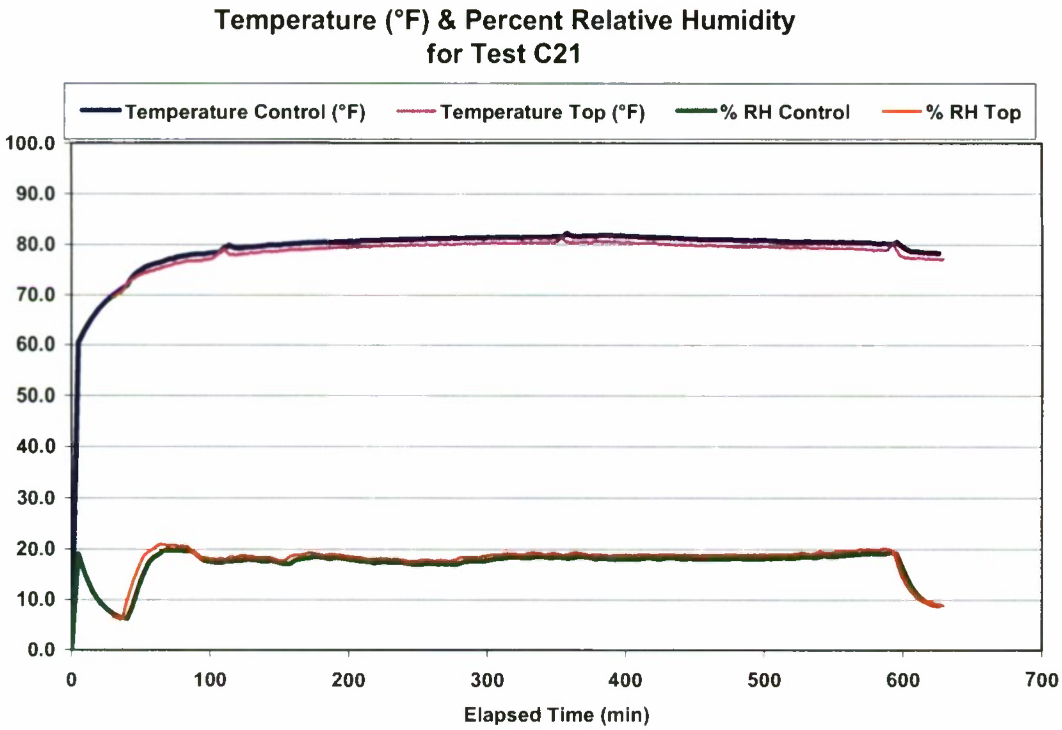
B.21 HD Efficacy A Test (Run 20 & 22 Scoping): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



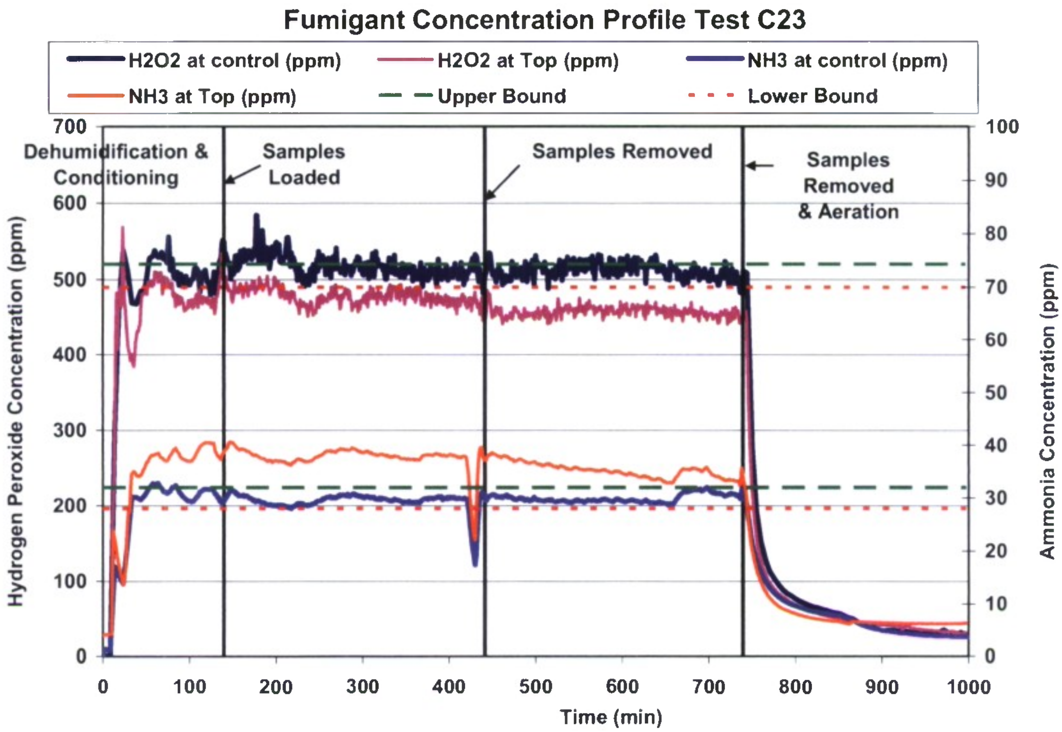


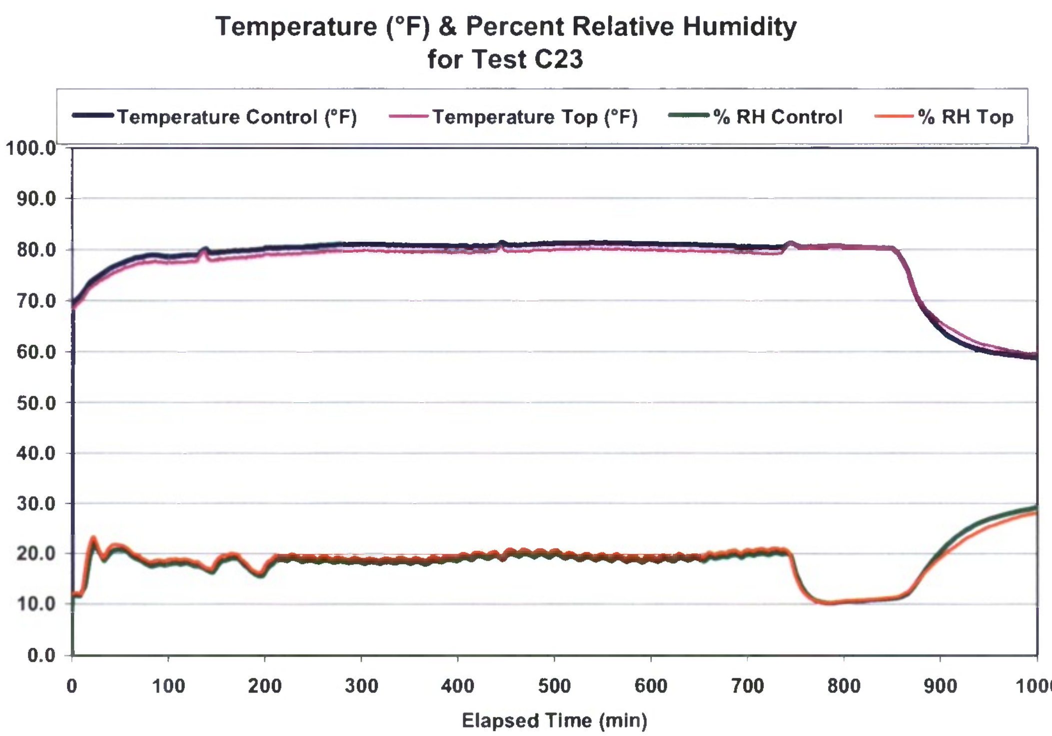
B.22 HD Efficacy B Test (Run 21 & 22 Scoping): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts



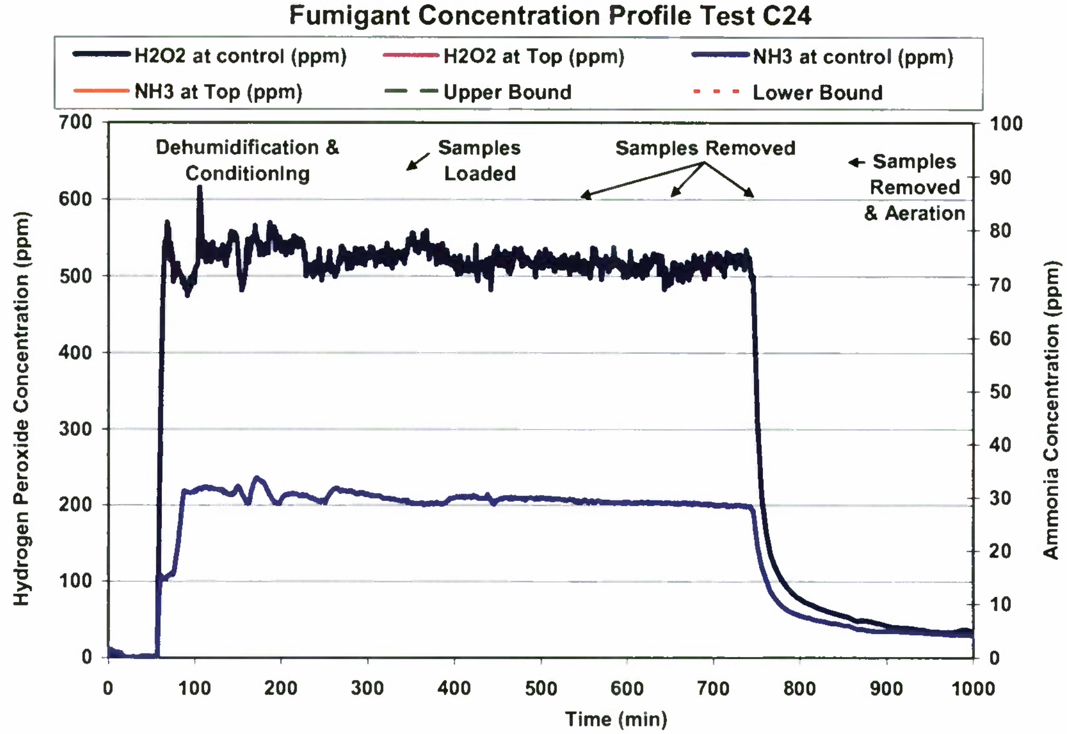


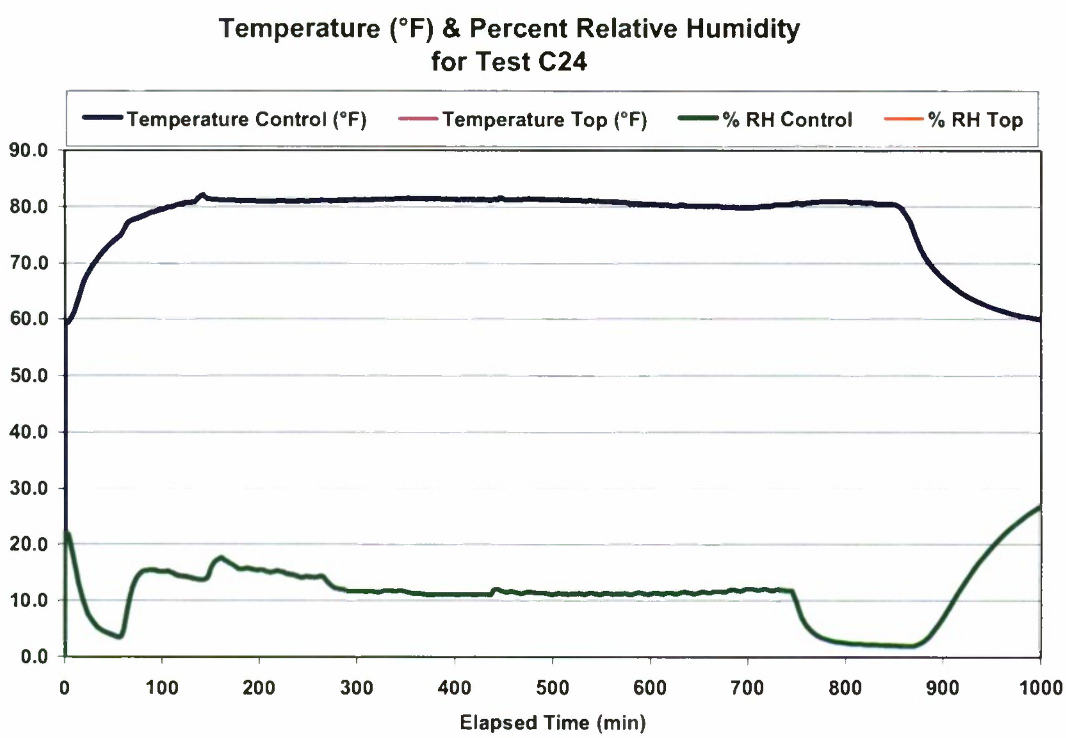
B.23 HD Efficacy A Wipe Test (Run 23): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





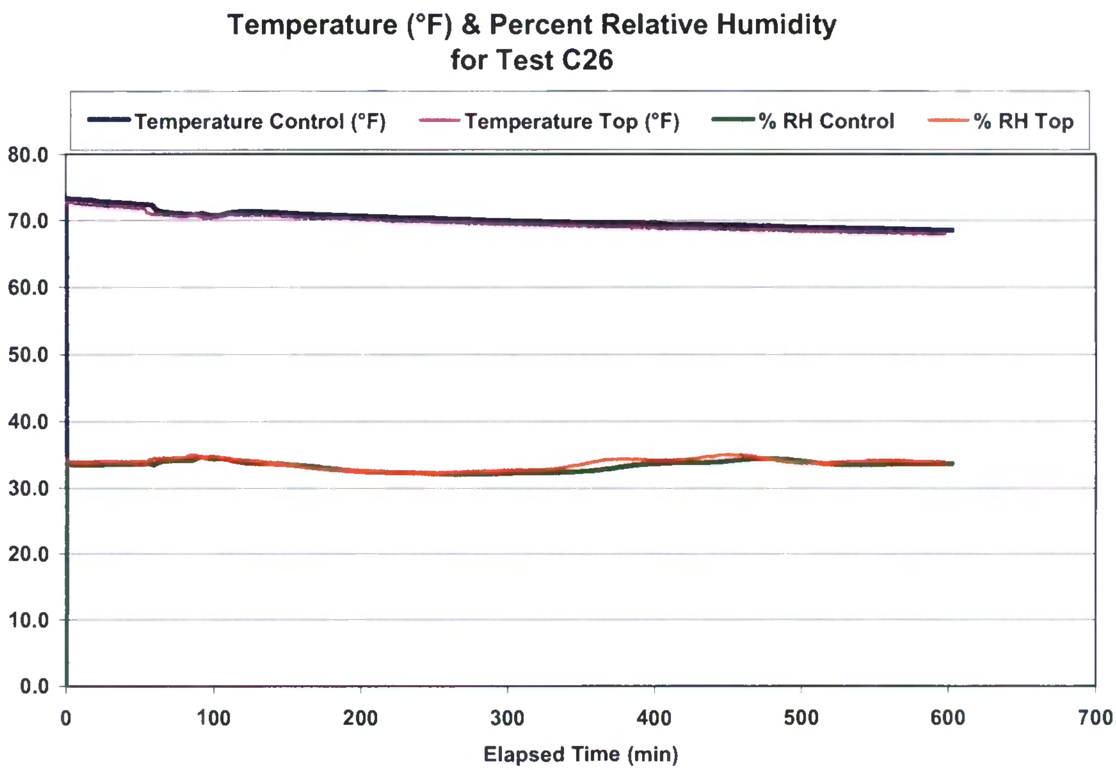
B.24 HD Efficacy B Wipe Test (Run 24): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts





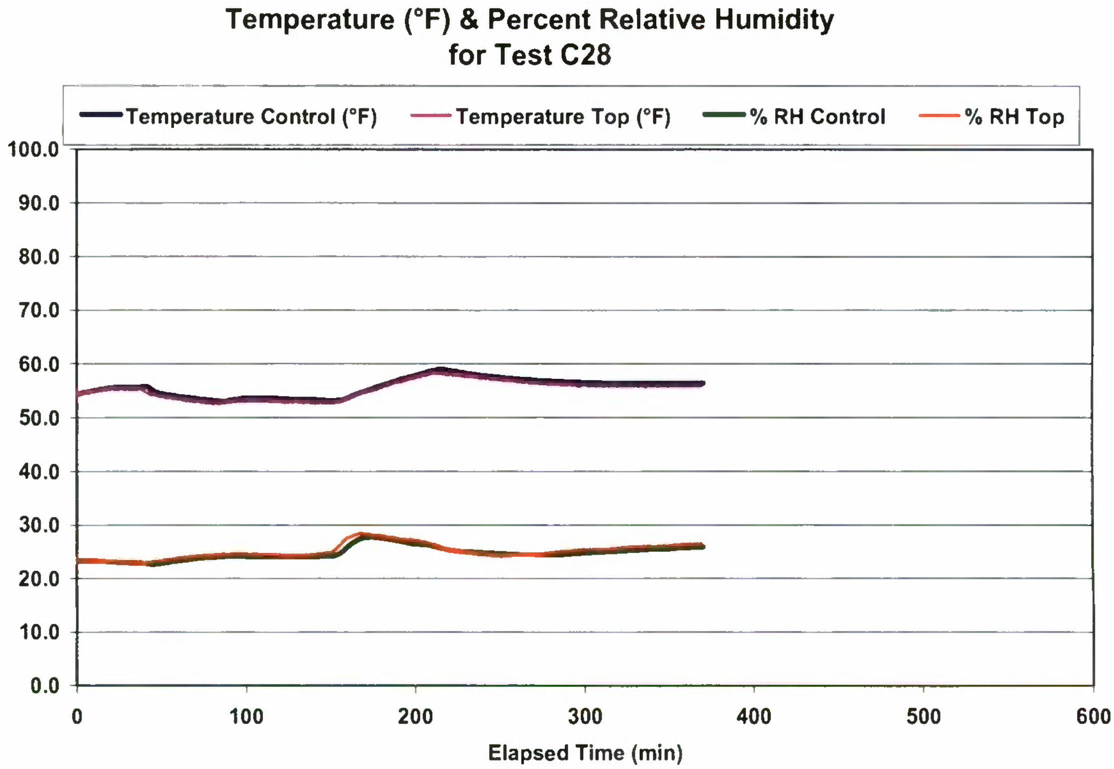
B.25 TGD Ambient Baseline Test (Run 26): Fumigant Concentration, and Temperature and Relative Humidity Process Control Charts

This was a baseline test; there was no measured fumigant concentration.

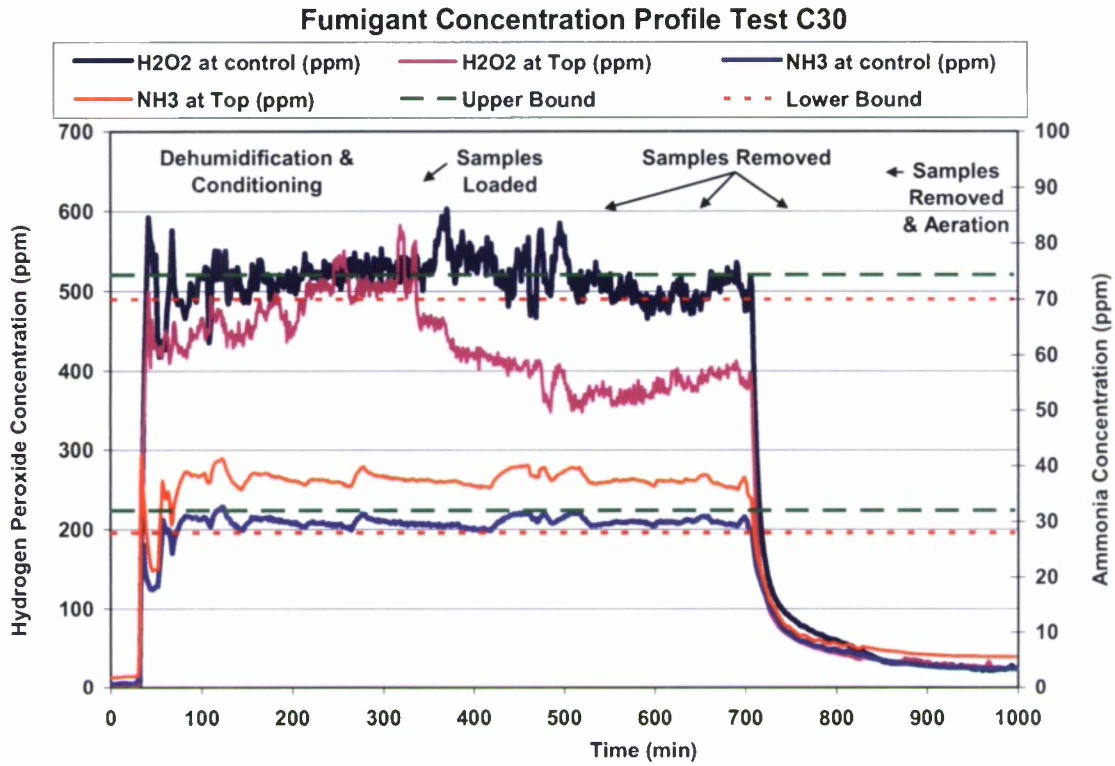


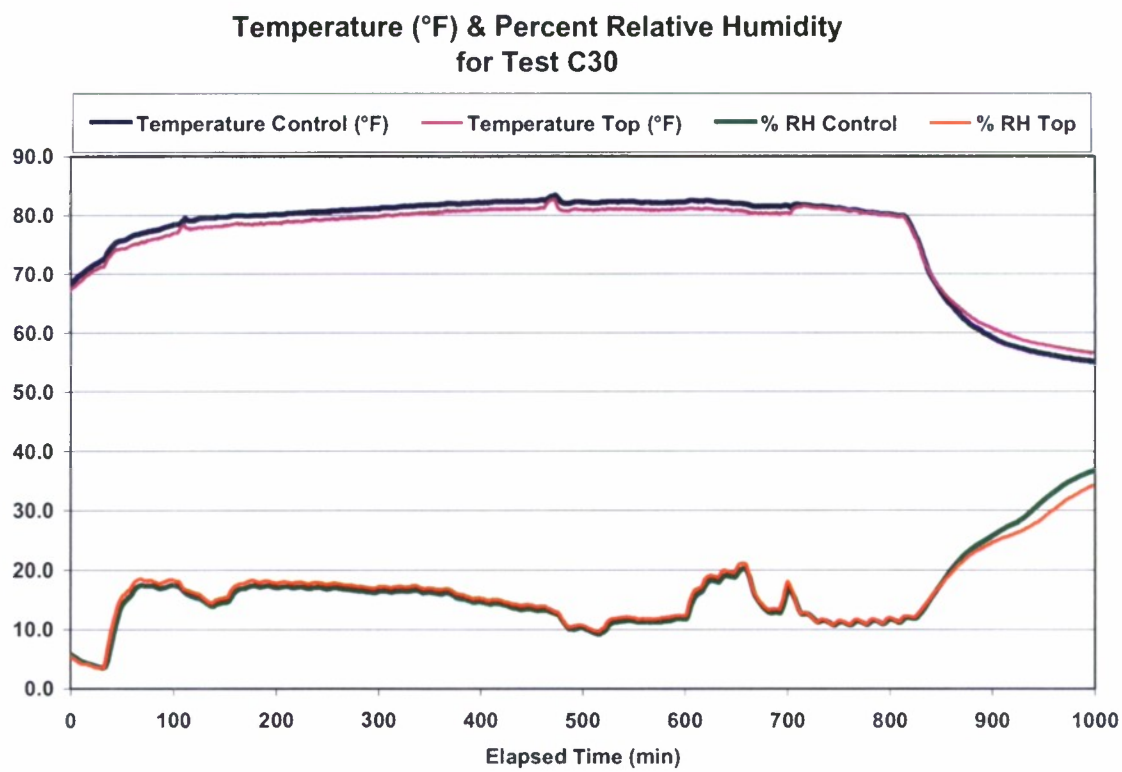
B.26 TGD Baseline Test (Run 28)

This was a baseline test; there was no measured fumigant concentration.



B.27 VX Repeat Test (Run 30)





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APPENDIX C
ANALYTICAL INSTRUMENTATION PARAMETERS

C.1 Vapor Analysis Parameters

C.1.1 Thermal Desorption System Parameters

Table C.1.1: TDS Parameters

Agent	Purge Trap In Line	Purge Split	Desorb 1 Split	Trap Split	Tube Desorb Split (mL/min)	Trap Desorb Split (mL/min)
GD 1	True	False	False	False	0	0
HD	False	True	True	True	50	50
VX 2	True	False	False	False	0	0

1 GD parameters apply to TGD as well
2 VX was analyzed as the G analog

Most TDS parameters were kept constant for all agents, specifically:

- operating mode – standard two stage
- idle split – true
- standby flow – 20 mL/min
- purge time – 1 min
- minimum carrier pressure – 5 psi
- purge flow – 20 mL/min
- ola split flow – 20 mL/min
- oven temperature 1 – 250 °C,
- desorb time 1 – 5 min
- desorb 1 trap in line – true
- desorb 1 flow – 20 mL/min
- desorb time 2 – 0 min
- dry purge time – 1 min
- trap low – 10 °C
- trap high – 300 °C
- trap hold – 3
- column flow – 2 mL/min
- desorb flow – 80 mL/min
- flow path temperature – 200 °C
- GC cycle time – 13 min

C.1.2 Gas Chromatograph Parameters

Initial Oven Temp: 50 °C
Initial Oven Time: 1.0 min
Oven Equilibration Time: 0.5 min
Oven Rate: 35.0 °C / min
Final Oven Temp: 270 °C
Final Oven Time: 2.71 min
Run Time: 10 min
Injection: splitless

Carrier Pressure: 9.54 psi
Purge Flow: 50.0 mL/min
Purge Time: 999.99 min (a requirement for Unity / Ultra TDS)
Total Flow: 54.8 mL/min
Carrier Gas: Helium
Initial Column Flow: 2.0 mL/min

C.1.3 Pulsed FPD Parameters

Table C.1.3.1: pFPD Channel 1/2 Parameters

Agent	Attenuation	Mode	PMT Voltage
GD 1	64 / 256	P / P	450
HD	128 / 128	S / S-2	550
VX 2	128 / 128	P / S	550

1 GD parameters apply to TGD as well
2 VX was analyzed as the G analog

Table C.1.3.2: pFPD Mode Parameters

Mode	A-Start	A-Stop	Alpha	B-Start	B-Stop	Sqrt
P	6.00	10.00	0.000	4.00	5.00	OFF
S	6.00	24.00	0.000	0.00	0.10	OFF
S-2	6.00	24.00	0.000	0.00	0.10	ON

Note: Many pFPD parameters were kept constant for all agents, specifically:

Channel parameters:

- zero value – 0
- interpolation mode – linear
- igniter current – 3.00
- trigger level – 100
- range – 100

Gas flow parameters:

- hydrogen – 11.4 mL/min
- air – 13.3 mL/min
- nitrogen makeup – 9.8 mL/min

Mode – constant makeup flow

Detector temperature – 300 C

C.2 Contact Analysis Parameters

C.2.1 GD / TGD Extract Analysis

GC Parameters:

- Initial Oven Temp: 60 °C
- Initial Oven Time: 2.5 min
- Oven Equilibration Time: 1.0 min
- Oven Rate: 20.0 °C / min
- Final Oven Temp: 270 °C
- Final Oven Time: 0 min
- Run Time: 13 min
- Injection: pulsed splitless
- Injection Temp: 265 °C
- Carrier Pressure: 15.55 psi
- Pulse Pressure: 25.0 psi
- Pulse Time: 2.0 min
- Purge Flow: 50.0 mL/min
- Purge Time: 3.0 min
- Total Flow: 54.3 mL/min
- Saver Flow: 20.0 mL/min
- Saver Time: 3.0 min
- Carrier Gas: Helium
- MSD Transfer Line Temp: 270 °C
- Injection Volume: 2.0 μL
- Viscosity Delay: 5 sec
- Plunger Speed: slow
- Post Injection Dwell: 0.25 min

MSD Parameters:

- Tune: auto tune
- Acquisition Mode: SIM
- Solvent Delay: 4.0 min
- EM Offset: relative (tune + whatever required bringing EMV up to ~2500)
- Ion / Dwell: 69.0/100, 82.0/100, 99.0/100, 126.0/100
- Resolution: Low
- Quant Ion: 126.0
- MS Quad Temp: 150 °C
- MS Source temp: 230 °C

C.2.2 HD Extract Analysis

GC Parameters:

- Initial Oven Temp: 70 °C
- Initial Oven Time: 1.0 min
- Oven Equilibration Time: 1.0 min
- Oven Rate 1: 25.0 °C / min
- Final Oven Temp 1: 170 °C
- Final Oven Time 1: 0 min
- Oven Rate 2: 35.0 °C / min
- Final Oven Temp 2: 290 °C

- Final Oven Time 2: 1.57 min
- Run Time: 10 min
- Injection: pulsed splitless
- Injection Temp: 275 °C
- Carrier Pressure: 15.44 psi
- Pulse Pressure: 25.0 psi
- Pulse Time: 1.0 min
- Purge Flow: 50.0 mL/min
- Purge Time: 3.0 min
- Total Flow: 54.2 mL/min
- Saver Flow: 20.0 mL/min
- Saver Time: 3.0 min
- Carrier Gas: Helium
- MSD Transfer Line Temp: 300 °C
- Injection Volume: 3.0 μL
- Viscosity delay: 5 sec
- Plunger Speed: fast

MSD Parameters:

- Tune: auto tune
- Acquisition Mode: Scan
- Solvent Delay: 4.2 min
- EM Offset: relative (tune + whatever required bringing EMV up to ~2500)
- Low Mass: 35.0
- High Mass: 250.0
- Threshold: 500
- Sample #: 2
- Quant Ion: 160.0
- MS Quad Temp: 150 °C
- MS Source temp: 230 °C

C.2.3 VX Extract Analysis

GC Parameters:

- Initial Oven Temp: 70 °C
- Initial Oven Time: 1.0 min
- Oven Equilibration Time: 1.0 min
- Oven Rate: 25.0 °C / min
- Final Oven Temp: 290 °C
- Final Oven Time: 0.2 min
- Run Time: 10.0 min
- Injection: pulsed splitless
- Injection Temp: 275 °C
- Carrier Pressure: 16.46 psi
- Pulse Pressure: 25.0 psi
- Pulse Time: 1.0 min
- Purge Flow: 50.0 mL/min
- Purge Time: 1.0 min
- Total Flow: 54.5 mL/min
- Saver Flow: 20.0 mL/min
- Saver Time: 3.0 min
- Carrier Gas: Helium
- MSD Transfer Line Temp: 270 °C
- Injection Volume: 3.0 µL
- Viscosity delay: 5 sec
- Plunger Speed: slow

MSD Parameters:

- Tune: auto tune
- Acquisition Mode: SIM
- Solvent Delay: 4.0 min
- EM Offset: relative (tune + whatever required bringing EMV up to ~2500)
- Ion / Dwell: 114.0/100, 127.0/100, 139.0/100, 167.0/100
- Resolution: Low
- Quant Ion: 127.0
- MS Quad Temp: 150 °C
- MS Source temp: 230 °C

Blank

APPENDIX D
COUPON CHAIN-OF-CUSTODY (COC) CARD

All coupons were tracked from contamination through analysis. Two types of CoC cards were used: contact/ residual analysis and vapor analysis.

D.1 Contact and Residual Analysis CoC Card

The contact-hazard and residual agent cards identified the coupon for analysis, dish and the types of tests to be done. If the 15M and 60M contact-hazard and residual agent measurements were to be conducted, the comments stated three extract analyses.

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The Nation's Premier Chemical Biological Defense Research and Development Organization

Sample Chain-of-Custody (C-O-C) and Analysis Request Form
Hazardous Materiel Testing Facility (HMTF) Sample Processing Area (SPA)
Beach Point Road, Building E3726, Room 108, APGEA, MD 21010, 410 - 436 - 4124

	Client / Field Sample Identification	Date Sampled (mm/dd/yy)	Time Sampled (24 hr)	Sample Matrix	Sample Type	Number, Size & Type of Containers	Analytes / Reporting Limits	Comments	SPA Sample Identification
1	14-10-A-046-S-CON-1			S	test coupon	1 TUPPERWARE	GD	3 CONTACT ANALYSES	14-10-A-046-S-CON-1
2	14-10-A-047-B-CON-1			B	test coupon		GD	3 CONTACT ANALYSES	14-10-A-047-B-CON-1
3	14-10-A-048-A-CON-1			A	test coupon		GD	3 CONTACT ANALYSES	14-10-A-048-A-CON-1
4	14-10-A-049-C-CON-1			C	test coupon		GD	3 CONTACT ANALYSES	14-10-A-049-C-CON-1
5	14-10-A-050-P-CON-1			P	test coupon		GD	3 CONTACT ANALYSES	14-10-A-050-P-CON-1
6	14-11-A-051-B-CON-2			B	test coupon	1 TUPPERWARE	GD	3 CONTACT ANALYSES	14-11-A-051-B-CON-2
7	14-11-A-052-A-CON-2			A	test coupon		GD	3 CONTACT ANALYSES	14-11-A-052-A-CON-2
8	14-11-A-053-C-CON-2			C	test coupon		GD	3 CONTACT ANALYSES	14-11-A-053-C-CON-2
9	14-11-A-054-P-CON-2			P	test coupon		GD	3 CONTACT ANALYSES	14-11-A-054-P-CON-2
10	14-11-A-055-S-CON-2			S	test coupon		GD	3 CONTACT ANALYSES	14-11-A-055-S-CON-2

Collected / Relinquished by: (sign & print)	Date (mm/dd/yy)	Time (24 hr)	Location of Transfer:	Received by: (sign & print)
Jim Hendershot			E3566	J. Kirk Williams
Relinquished by: (sign & print)	**Date (mm/dd/yy)**	**Time (24 hr)**	**Location of Transfer:**	**Received by: (sign & print)**
Relinquished by: (sign & print)	**Date (mm/dd/yy)**	**Time (24 hr)**	**Location of Transfer:**	**Received by: (sign & print)**

- for notes ❶ through ⓾ see back of form

D.2 Vapor Analysis CoC Card

The vapor-hazard cards identified the coupon for analysis, material type, and dish. In addition, the key vapor-sampling details were recorded on the CoC form including: DAAMS tube serial number, beginning and ending flow rate used, and calculated average flow rate during sampling period.

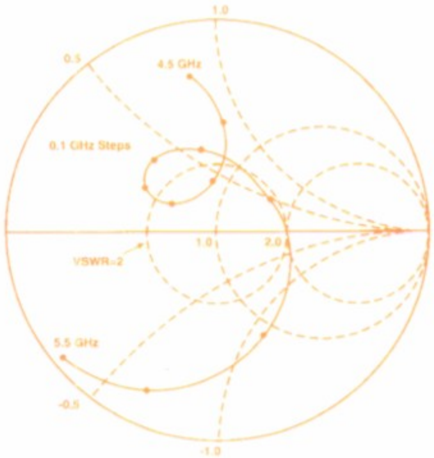
EDGEWOOD CHEMICAL BIOLOGICAL CENTER
The Nation's Premier Chemical Biological Defense Research and Development Organization

Sample Chain-of-Custody (C-O-C) and Analysis Request Form
Hazardous Materiel Testing Facility (HMTF) Sample Processing Area (SPA)
Beach Point Road, Building E3726, Room 108, APGEA, MD 21010, 410 - 436 - 4124

	Client / Field Sample Identification ❶	CUP	Date ● Sampled (mm/dd/yy)	Time ● Sampled (24 hr)	Sample ● Matrix	Sample ● Type	Number, Size ● & Type of Containers	Analytes / Reporting ● Limits	Comments ●	SPA Sample ● Identification	Sampling Time (min)	Beginning Flow Rate (mL/min)	Ending Flow Rate (mL/min)
1	14-09-A-041-B-VAP-1	1			B	vapor	Tube MI#______	GD	vapor analysis	14-09-A-041-B-VAP-1			
2	14-09-A-042-A-VAP-1	2			A	vapor	Tube MI#______	GD	vapor analysis	14-09-A-042-A-VAP-1			
3	14-09-A-043-C-VAP-1	3			C	vapor	Tube MI#______	GD	vapor analysis	14-09-A-043-C-VAP-1			
4	14-09-A-044-P-VAP-1	4			P	vapor	Tube MI#______	GD	vapor analysis	14-09-A-044-P-VAP-1			
5	14-09-A-045-S-VAP-1	5			S	vapor	Tube MI#______	GD	vapor analysis	14-09-A-045-S-VAP-1			
6	14-12-A-056-S-VAP-2	6			S	vapor	Tube MI#______	GD	vapor analysis	14-12-A-056-S-VAP-2			
7	14-12-A-057-B-VAP-2	7			B	vapor	Tube MI#______	GD	vapor analysis	14-12-A-057-B-VAP-2			
8	14-12-A-058-A-VAP-2	8			A	vapor	Tube MI#______	GD	vapor analysis	14-12-A-058-A-VAP-2			
9	14-12-A-059-C-VAP-2	9			C	vapor	Tube MI#______	GD	vapor analysis	14-12-A-059-C-VAP-2			
10	14-12-A-060-P-VAP-2	10			P	vapor	Tube MI#______	GD	vapor analysis	14-12-A-060-P-VAP-2			

Collected / Relinquished by: (sign & print) ●	Date (mm/dd/yy)	Time (24 hr)	Location of Transfer:	Received by: (sign & print)
Jim Hendershot			E3566	J. Kirk Williams
Relinquished by: (sign & print)	Date (mm/dd/yy)	Time (24 hr)	Location of Transfer:	Received by: (sign & print)
Relinquished by: (sign & print)	Date (mm/dd/yy)	Time (24 hr)	Location of Transfer:	Received by: (sign & print)

- for notes ❶ through ⓾ see back of form



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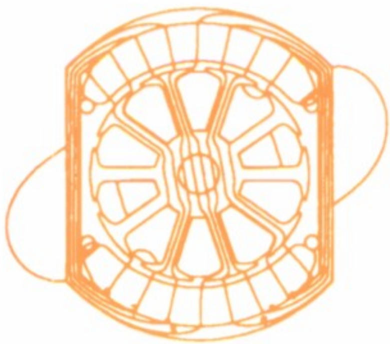

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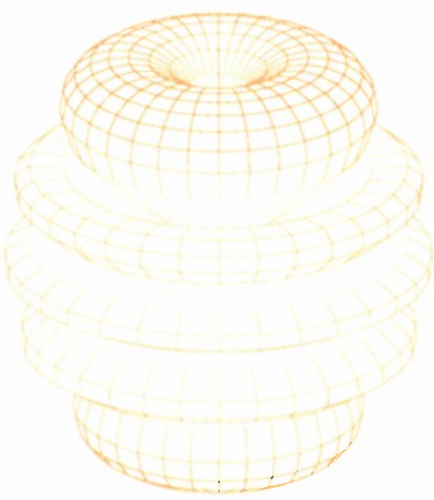

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